A study of cultural models in automotive HMI: Framework for accommodating cultural influence

Submitted By

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GLOSSARY OF TERMS

Term	*Description*
BSREC	Biomedical & Science Research Ethics Committee
CUI	Cultural User Interface
CAUI	Culturally Adapted User Interface
CY	Calendar Year
DR	Development Research
GUI	Graphical User Interface
GOMS	Goals Operator Methods
HMI	Human Machine Interface
HCI	Human Computer Interface
IS	Information System
IVIS	In-Vehicle Information System
LOC	Locus of Control
LTO	Long Term Orientation
MAS	Masculinity
MMI	Man Machine Interface
MY	Model Year
NPD	New Product Development
NPI	New Product Introduction
PC	Personal Computer
PD	Product Development
PU	Perceived Usefulness
PALS	Product Attribute Leadership Strategy
RDP	Research Development Process
R&D	Research and Development
SAE	Society of Automobile Engineers
SEC	Socio-Economic Classification
SC	Social Class
SUV	Sports Utility Vehicle
SAE	Society Of Automobile Engineers
TQM	Total Quality Management
TDP	Technology Development Process
UK	United Kingdom
UE	Usability Engineering
UCD	User Centered Design
UAI	Uncertainty Avoidance
UI	User Interface
VSM	Value Survey Module

DECLARATION

I hereby confirm that all of the research contained within this Engineering Doctorate Innovation report is my own work, with acknowledgements for technical support given as appropriate in the text. This work has not been previously submitted for any other academic degree or qualification.

Tawhid Khan
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I would like to thank my family, especially my wife and children, whose support and patience has meant more to me, especially over the last few years, than I can probably ever express. Thank you all for the kind support and patience throughout the assignment.

Finally, I would like to dedicate this work to my beloved father who passed away during 1996 in a car accident. If he is alive, he would have been the happiest man to see my work.

PUBLICATIONS

Innovation, relevance, and validity associated with this research are demonstrated by placing the research findings in the public domain. This innovation report illustrates how the research findings were made public, debated and defended. This report includes five journal papers (of which two are yet to be published) and one conference paper, which are referred throughout the main body of text. The papers should be read in conjunction with the main discourse. The paper published as outputs of the research was as follows:

Woodcock, A., Wellings, T., Binersley, J., Tovey, M., Robertson, D., Khan, T., (2012), "Identifying HMI requirements from field trials and the accounts of early adopters of low carbon vehicles", *Proceeding of the Contemporary Ergonomics and Human Factors 2012*, Blackpool, UK, 16-19thApr 2012, pp. 401-408. ISSN: 9780415621526.

Khan, T., Williams, M. A., Wellings, T., Robertson, D. Binersley, J., (2012), "Designing the Human Machine Interface to Address Range Anxiety", *WEVA Journal*, vol. 1, pp. 216-225, ISBN: 9781622764211.

Khan, T., & Williams, M. A., (2014), "A Study of Cultural Influence in Automotive HMI: Measuring Correlation between Culture and HMI Usability", *SAE International Journal of Passenger Cars – Electronics & Electrical System*, vol. 7, no.2, doi: 10.4271/2014-01-0263.

Khan, T., Williams, M.A., Pitts, M., (2016), "Cross-Cultural Differences in Automotive HMI Design: A Comparative Study between UK and Indian Users Design Preferences", *Journal of Usability Studies*, vol. 11, no.2, pp. 45-65.

Khan, T., Williams, M.A., Pitts, M., (2016), "A Study of Cultural Models in Automotive Human Machine Interface: Framework for Accommodating Cultural Influence", *IEEE Transaction of Human Machine System (THMS)*, under peer review.

Khan, T., Williams, M.A., Attridge, A., (2016), "Improving driver Learnability and Satisfaction with Culturally Adapted Automotive Human Machine Interfaces", *International Journal of Vehicle Design (IJVD),* InderScience publication, under peer review.

ABSTRACT

This doctoral innovation report presents a research study examining the importance of understanding automotive users' cultural values and their individual preferences for HMI features and functionalities. The goal of this research was to explore how a cultural model can be applied in the development of automotive HMI solutions and future design localisation. To meet this goal, it was necessary to (1) identify the characteristics of the Hofstede cultural model; (2) identify the differences in cultural values using the model; (3) identify differences in HMI design preferences, usability and task performances across automotive user groups; (4) identify the potential success of a culturally adapted automotive HMI solution in automotive user acceptance and satisfaction.

To explore the differences between users from two cultural regions, India and the UK, a series of user-centered HMI evaluation studies are conducted in which participants from each cultural region evaluate representative HMI samples. The outcomes of the user studies generate good quality data about automotive users' cultural values and its relationship with vehicle user interface usability, task performances, and their feature preferences. The results are used in the development of a conceptual culturally adapted HMI design solution. This conceptual design is evaluated during the application phase of the research in order to explore whether such a design solution has a greater level of learnability and usability compared to the conventional solution when evaluated by Indian drivers. The results are also analysed to identify specific cultural traits that may influence the intention to use such solution in emerging markets like India.

The outcome of the study shows different cultural groups have different behavioural tendencies and performances while using vehicle HMI solutions and have differences in expectations in design, suggesting an influence of culture on the perception of vehicle user interface technology. The analysis also highlights a preference for the culturally adapted automotive HMI solution when Indian drivers are provided with a choice between this and a non-adapted conventional solution. This leads to the conclusion that an understanding of cultural biases can influence design localisation and, as such, culturally-generated theories and recommendations can be applied as a basis for future automotive HMI design and development.

1 INTRODUCTION

1.1 Chapter Overview

The purpose of this chapter is to describe the construct of the overall innovation report. The chapter sets out the background information, primarily the industrial context of the research project, offers a justification of the need for the research, and identifies the research question and associated objectives after needs analysis. This chapter also describes the outlines of the overall doctoral research project portfolio and defines associated terminologies.

1.2 Research Background

Culture is recognised as having a significant influence on human behaviour as it provides people with a sense of identity and an understanding of acceptable attitudes and behaviour within society (Khan & Williams, 2014). In many ways, culture affects our context of use and perception of a product, thus affecting everyday lives. For example, psychologists have found that culture influences memory, judgment, perception and decision making (Mann *et al*, 1985; Middleton, 2002; Nisbett, 2003). Hence, culture is the logical starting point for the examination of user behaviour (Engel *et al*, 1993).Cultures are primarily formed by specific social facts, including religion, politics, rituals, values and language (Coventry *et al*, 2004; Bourges-Waldegg & Scrivener, 1998). Applying this definition to the interaction with a machine, culture has to be regarded as a powerful variable affecting users' expectations and behavioural possibilities, thus determining people's response to that machine, including misuse or no use at all (Coventry *et al*, 2004).

With respect to automotive Human Machine Interface (HMI), the majority of current design largely focuses on the needs and preferences of drivers from Western markets and assumes a one-size-fits-all model. However, the driving environment and driver attitudes in regions such as China and India are different from the West; as such Western models of automotive HMI design may not necessarily fit the needs of the region's drivers (Khan *et al*, 2016).

Considering regional differences, particularly cultural aspects of HMI design, is important in the current economic climate because all automotive manufacturers are looking beyond their traditional Western markets. With this in mind, if an automotive manufacturer wishes to expand into new regions, "it is imperative that they understand the role of culture and its effect on driver perception of, attitude towards, and preferences for user interfaces in the vehicle" (Khan *et al*, 2016, p46). This understanding is instrumental in facilitating technology uptake and improving design localisation (Carey, 1998).

The field of Human Computer Interaction (HCI) applies cultural models in many different ways to understand cultural influences in the user interface (UI) design. Cultural models are used to identify information that is cross-culturally appropriate, avoid cross-cultural mistakes which can cause offence, assess the degree of localisation that will be necessary and evaluate the suitability of international interface (Hoft, 1996). For example, cultural models are used to compare websites of different countries (Gould *et al,* 2000; Callahan, 2005) and to explain the acceptance and adoption of technologies in different countries (Coventry *et al,* 2004; Barnett & Sung, 2005; Maitland & Bauer, 2001). Therefore, lessons learned concerning the relationship between HCI and cultural models can potentially benefit automotive HMI design.

1.2.1 HCI vis-à-vis HMI

In this research project, HCI is regarded as a field of display based research study (e.g., computer websites, app portals etc.) not a type of interface product. As a field of research, HCI studies the way which humans use computational artefacts, systems and associated infrastructure and seek to improve human-computer interaction by improving the usability of computer interfaces (Grudin, 1992). As such, HCI does not consider other machines or artefacts apart from computers. HMI, on the other hand, is commonly used for defining a point of control for a human to a machine driven process and can be regarded as context-driven user interface product. For example, within an automotive driving context, an HMI product can range from a few push button one DIN radio to a touchscreen integrated complex display system or even a brake pedal or seat adjustments mechanical switches which requires no display output. In heavy machinery industries such as electrical installation, SCADA-integrated panel view is also regarded as HMI which requires no display. Thus, HMI can be generalised for the interaction between human and machine not just as graphical display user interface. However, in automotive industries, HMI and

Infotainment are interchangeably used mostly to describe secondary functions that allow the driver to interact with the vehicle information system (e.g., GPS Navigation, Center Display, Instrument cluster, Heads up Display, switch control panel etc.). HMI functions are among the most readily visible features of the vehicle.

Doyle (2002), stated that, although HCI can be regarded as a subclass of HMI, they are, however, relatively distinct, due to the emphasis on different subject matter. For example, HCI emphasises more on the cognitive process during an interaction which is aided by cognitive science (Aitkenhead & Slack, 1985), while HMI put more emphasis on ergonomics and is aided by human factors. Doyle (2002) and Aitkenhead & Slack (1985) also argued that, although machines are likely to be controlled by computer interfaces, essential issues of ergonomic considerations such as appearance, configuration, size, illumination and the tactile feel of electromechanical controls are not considered by HCI. Furthermore, Heimgartner (2012) and Jacko (2012) stated that HMI falls into the school of information science, which deals with all aspects of information, whereas according to Kuhlen (1991) and Hammwohner & Kuhlen (2004), HCI falls into computer science, and only cares about the user and method of using computational aspects of information processing system.

Having analysed the definitions and differences, this study concluded that although HCI and HMI have different emphases and belongs to different disciplines of study, however, both have a common focus on design; evaluation and implementation of display interactive system (if exists within HMI) and addresses user experience and usability related issues for effective design solutions (Sisira & McDonald, 2006). Furthermore, both domains utilises user interfaces (UI) to initiate tasks with display system and the system responds with results to the user to solve problems or accomplish predefined tasks. Therefore, it can be argued that although context and type of display terminal use are different between HCI and HMI (in the context of vehicle Infotainment and GPS Navigation functions), the process of means to achieve UI tasks can be same. To achieve design efficiency, both domains focuses on identifying user abilities with the display information system and then applies that knowledge to improve user interaction with the systems in order to optimise user's well-being and overall system performance. Therefore, automotive design research is appropriate for HMI as well as HCI and there is an interdependent amongst these subject matters.

1.3 Research Need

The importance and potential benefit of cross-cultural adaptability in the design of vehicle HMI systems is acknowledged in several previous studies (e.g., comparison between the US and China in perceived hazard response to warning components and configurations by Lesch *et al,* 2009; comparison between Swedish and Chinese drivers in the design of advanced driver assistance systems by Lindgren *et al,* 2008;comparison of Australian and Chinese drivers in the use of In-vehicle Information Systems by Young *et al,* 2011; comparison between UK and Indian drivers in the usability of HMI systems by Khan & Williams, 2014; comparison between German and Chinese drivers in the use of GPS Navigation systems by Heimgartner, 2007 and Heimgartner & Holzinger, 2005; comparison between the UK, Malaysian, Chinese and Japanese users in In-Vehicle Navigation Systems (IVNS) by Mohd Hasni, 2012). These studies highlight a range of cultural differences amongst participating groups, in terms of their UI preferences, GPS Navigational directions, driving and task management styles that are relevant to HMI design. For example, it was found that Chinese drivers prefer greater speed in screen formation and information density compared to German or English users (Heimgartner, 2007; Heimgartner & Holzinger, 2005). Similar results have also been found by Khan & Williams, (2014), where vehicle Bluetooth and GPS Navigation systems specifically designed to suit the visual perception and information decoding abilities of certain cultures (e.g., UK) are found to negatively influence the ability of people from another culture (e.g., India) to successfully interact with the system, as measured by task completion times and number of errors made. Young *et al*, (2011) found that Chinese drivers place less emphasis on safety and driver distraction than on the appearance or aesthetic appeal of the HMI compared to Australian users. Mohd Hasni (2012), observed differences in vehicle GPS Navigational instruction across the UK, Malaysia, China, and Japan, suggesting the need to support for personal preferences when designing IVNS (In Vehicle Navigation System) interfaces. At present, however, there is limited understanding of the nature of observed differences, particularly their causes and effects relative to other factors. As such, there is a lack of recommended guidelines and tools available to deal with cultural issues in the automotive HMI design.

Previous HCI researches applied Hofstede's theory to explain existing differences in design and to attempt to create tools and guidelines by which designs can be made more culturally appropriate for web interfaces. However, little has been done to understand how cultural theories can be applied in automotive HMI and, indeed, what aspects of these theories and models can be applied in order to ascertain the types of tools, architecture, and guidelines required for designing culturally appropriate vehicle HMI solutions. Therefore, to mitigate this gap, a user-centered research study is required amongst automotive user groups to explore how cultural model can be utilised in the design. In order to achieve this goal, it is necessary to: (1) identify the characteristics of a cultural model; (2) understand its function and attributes; (3) identify the differences in cultural values using the model between drivers of the cultural groups; (3) identify differences in HMI design needs and preferences across drivers for cultural groups; (4) develop culturally adapted HMI design solutions to assess system effectiveness in the markets.

1.4 Research Question

With the research gap identified in the preceding section, the problem addressed in this doctoral engineering research is:

"*How can a cultural model be applied in the development of automotive Human Machine Interfaces and used to design culturally adapted solution for user acceptance and satisfaction*?"

In order to answer the research question the following research objectives are established:

1. To investigate whether there are any differences in cultural values and orientation across automotive users from cultural groups.

2. To investigate whether there are any differences exist during the use of an HMI system amongst users from cultural groups.

3. To investigate whether there are any differences in automotive HMI design needs and preferences across automotive users from cultural groups.

4. To assess what can be learned from cultural theories and methodologies derived by HCI practitioners that will help in the design of automotive HMI solutions.

5. To evaluate whether culturally generated research findings will help automotive manufacturers to implement cross-cultural automotive HMI design solutions.

6. To evaluate whether culturally adapted automotive HMI solutions have greater success in automotive HMI users' acceptance compared to non-adapted solutions.

1.4.1 Definition of Acceptance and Acceptability

In this research 'acceptance' is referred to as behavioural tendencies towards accepting a culturally adapted HMI solution that, is displayed in the form of observable behaviour (Franken, 2007), during HMI evaluation studies by a participating cultural group. Literature review suggests, several authors attempted to clarify the distinction between 'acceptance' and 'acceptability'. For example, they defined 'acceptance' as the "prospective judgement of measures to be introduced in the future" (Schade & Schlag, 2003, quoted in Regan *et al,* 2014, p15), while 'acceptability' is a subjective measurement that does not incorporate system experience and therefore an attitude construct (Regan *et al*, 2014). Jamson (2010) defined, 'acceptance' as to how a user would use a system while 'acceptability' is how much he/she liked it. Regan *et al*, (2014) also argued that 'acceptance' and 'acceptability' are used interchangeably in the literature. As such, 'acceptability' can be characterised as potential 'acceptance' when designing a product (Regan *et al*, 2014). Burnett & Diels (2014) emphasised importance of understanding, acceptance when considering "related issues of usability and satisfaction" (quoted in Regan *et al*, 2014, p138), of an automotive system. The numerous ways of assessing acceptance found in the literature review are summarised in Table 1. Most authors used more than one measurement process to assess acceptance; usually based on interviews, focus groups, logged data and physiological measures etc. (Adell, 2009).

Table 1: Five categories of acceptance
(Adapted from Adell, 2009, p32and Acceptance definition defined by Regan et al, 2014, p13)

No	*Categories*	*Definition of Acceptance*	*Author*
1	Using the word 'Accept'	The degree to which a law, measure or device is accepted	Risser *et al*, (1999)
2	Satisfying needs and requirements	The degree to which a solution or system satisfy all the needs and requirements of users (usefulness of the system)	Nielsen, 1993
3	Sum of attitudes	"What the objects or contents for which acceptance is measured are associated to for the user"	Risser & Lehner (1998) in Regan *et al*, (2014, p13)
4	Willingness to use	"Intention to adopt an application"	Chismar & Wiley-Patton (2003) in Regan *et al,* (2014, p13)
5	Actual use	The demonstrable willingness by a user group to employ technology for the task, it is designed to support	Dillon & Morris (1996) in Regan *et al,* (2014)

Although measurement of acceptance can be related to the definition categories defined in Table 1, however, the literature review could not provide any further information about the meaning of acceptance using 'accept', attitudes' and 'willingness' (first, third and fourth category). This is also acknowledged by Adell (2009). Furthermore, the National Highway Traffic Safety Administration (NHSTA) strategic plan, 1997-2002 stated that, driver acceptance should be analysed in terms of ‘Ease of use’, ‘Ease of learning’, ‘perceived value’, ‘driving performance’ and perception of the system (Najm *et al*, 2006; Adell, 2009). These recommendations suggest a system should satisfy the needs and requirements of the driver during the actual use (the second and fifth category definition). To support these, Adell (2009) proposed that driver acceptance can be defined as “the degree to which an individual incorporates the system in his/her driving, or, if the system is not available, intends to use it” (quoted in Regan *et al*, 2014, p18). This definition clarifies that, a driver does not have to like to use the system to demonstrate acceptance (Regan *et al*, 2014). As long as he/she ‘tolerates’ its use then it is sufficiently acceptable (Regan *et al*, 2014). The definition also implies that, there are different degrees of acceptance and is not limited to, acceptance or no acceptance, but is of a more continuous nature (Adell, 2009). However, this definition stresses the importance of assessing a system development by addressing ‘intention to use the system’ if it is available (Regan *et al*, 2014). This leads to user subjective evaluation of the proposed culturally adapted UI solution for the project and can be referred as how pleasant the culturally adapted design would be to the regional driver so that they are subjectively satisfied when using the solution and they use it during their journey (potential acceptance). To ascertain driving context, Regan *et al,* (2014), clarified that ‘acceptance’ is tightly connected to the demonstration of judgement of the solution. As such, general liking of the proposed solution will not be the ‘acceptance’; to accept the solution, “the individual has to incorporate the system in his/her driving” (Adell, 2009, quoted in Regan *et al*, 2014, p18). Adell also suggested that potential solution design should facilitate the importance of driver-centered view to gain driver understating of the system.

1.4.2 Definition of Satisfaction

ISO9241-11 defines satisfaction as freedom from discomfort and positive attitudes towards the use of a product or system. ISO/IEC 25010 broadened the scope of this definition to encompass the overall user experience. As such, satisfaction is now part of the definition of usability in ISO/IEC 25010 (Bevan, 2010). Bevan (2010) stated that, with new ISO definition, satisfaction currently breaks down into four characteristics: purpose accomplishment, trust, pleasure, and comfort. With regards to automotive HMI in this research, the structure of the user ‘satisfaction’ construct can be viewed as a set of items relating to information content, menu structure and presentation layout (Muylle *et al*, 2004) and can be viewed as, one of the factors contributing to the usability (Nielsen, 2012). The construct of usability is described in Chapter 2 in more details. In this study, satisfaction is also regarded as user personal and subjective response that can be quantified by extending, traditional user's assessment of the 'Ease of use' (Bevan, 2010), as well as the 'Usefulness' and 'Ease of learning' of both an existing and culturally adapted HMI solution. The survey will measure more specific aspects such as efficiency, helpfulness, learnability and the pleasure of a system under test after using it by the user.

1.5 Outline of the EngD Portfolio

The research summarised in this innovation report is compiled from a series of portfolio submissions which demonstrate how the research programme has developed in order to answer the research question and objectives presented in Section 1.4.

Submission one: describes the findings and conclusions from literature research conducted into available methodologies to accommodate cultural models in UI design. A thorough review of the literature centers on three areas: Product design; Cultural influence on user behaviour; and Human Machine Interface, which adds to the knowledge in UI design methodologies to deal with cultural differences. The literature findings provide empirical information about the applicability of cultural models and concluded the use of Hofstede's cultural dimensions for future research use.

Submission two: describes the evaluation and selection of potential methodologies to develop a research model that can experiment cultural impact in automotive HMI. After carrying out a thorough literature review and developing hypotheses, the next steps in the research process are discussed in this submission. This submission also describes measurement techniques and data collection procedures that contribute to the development of the research design.

Submission three: details the work carried out during ethical consideration of the survey. The principle ethical philosophy includes treatment of participants with anonymity, avoiding any harm, fairness in distribution and providing information before and after the study. An application for ethical approval (BSREC) was submitted to the University of Warwick Ethics Committee. The application and associated supplementary information are included in this submission (Ref. REGO-2014-775).

Submission four: details the research findings related to objectives 1 and 2 and present the findings in a form designed to enable the research hypotheses and related analyses. The data resulting from the experiment are used to determine whether there are differences exists in driver's cultural values and his/her HMI user task performances amongst cultural groups (India and the UK).

Submission five: describes the research findings related to objectives 3 and 4. The study identifies automotive HMI design and feature preferences amongst UK and Indian participating groups. This submission describes how the design requirements are adapted from Marcus and Gould's (2000; 2015) cross-cultural web UI recommendations.

Submission six: outlines the application of culturally adapted automotive HMI solution in a vehicle platform. It describes how the findings helped to establish the design strategies for future vehicle programmes within sponsoring company and enquire whether the solution has greater success in Indian driver acceptance.

The overview of the portfolio submissions and how they fit into the context of the innovation report is shown in Figure 1.

1.6 Outline of the Innovation Report

A brief description of each of the chapters is provided to give a general outline to this innovation report.

Chapter one – Introduction: This chapter presents the background to the research problem and presents the research question and its associated objectives aimed at addressing the research problem.

Chapter two – Literature Review: This chapter details the background information required to be analysed and critiqued in order to provide a theoretical foundation from which to base the research study. After the detailed review of the relevant literature, research hypotheses are developed to meet the requirement of the research objectives.

Chapter three – Research Methodology: This chapter defines a research model. The requirements against hypotheses are used to select an appropriate research design to generate innovation and apply it to meet the requirements of the research question and objectives.

Chapter four – Cultural Context of Automotive HMI: This chapter presents the findings of a systematic usability experimentation and cultural value survey to identify cultural differences in user values and their ability to use automotive HMI solutions (between India and the UK). The chapter describes the relationship between cultural dimensions and automotive HMI usability factors.

Chapter five – Cultural Adaptation of Automotive HMI: This chapter describes how cultural theories and HCI web interface recommendations are utilised to investigate the drivers HMI design preferences between the two cultural groups and provides recommendations to mitigate these differences.

Chapter six – Application of Culturally Adapted HMI: This chapter describes how the optimised HMI feature requirements are applied in a real-time industrial environment (vehicle platform) and tested. This chapter describes the outcome of the user-centered studies carried out to examine the success of the culturally adapted HMI solution amongst Indian users.

Chapter seven – Industrial Application: This chapter discusses the implications of the project in relation to automotive industries. The chapter also describes the key output delivered to the project sponsoring company and how they benefited from the project.

Chapter eight – Discussion: This chapter brings together all the issues raised during the research and discusses them in relation to the research question and research objectives. This chapter discusses the extent to which the research goal has been met and whether the research question has been answered. The level of innovation generated by the research and its application is analysed along with limitations of the research.

Chapter nine – Conclusions: This chapter outlines the key conclusions drawn from the research and makes recommendations for future work.

1.7 Chapter Summary

This chapter has laid down the foundation of the innovation report. It introduced the overall research problem and raised research question that will be investigated in the literature review chapter. The need for this research has been defined and the structure of the report was outlined. On this foundation, the literature review part of the research can proceed with a detailed description of the knowledge and theories.

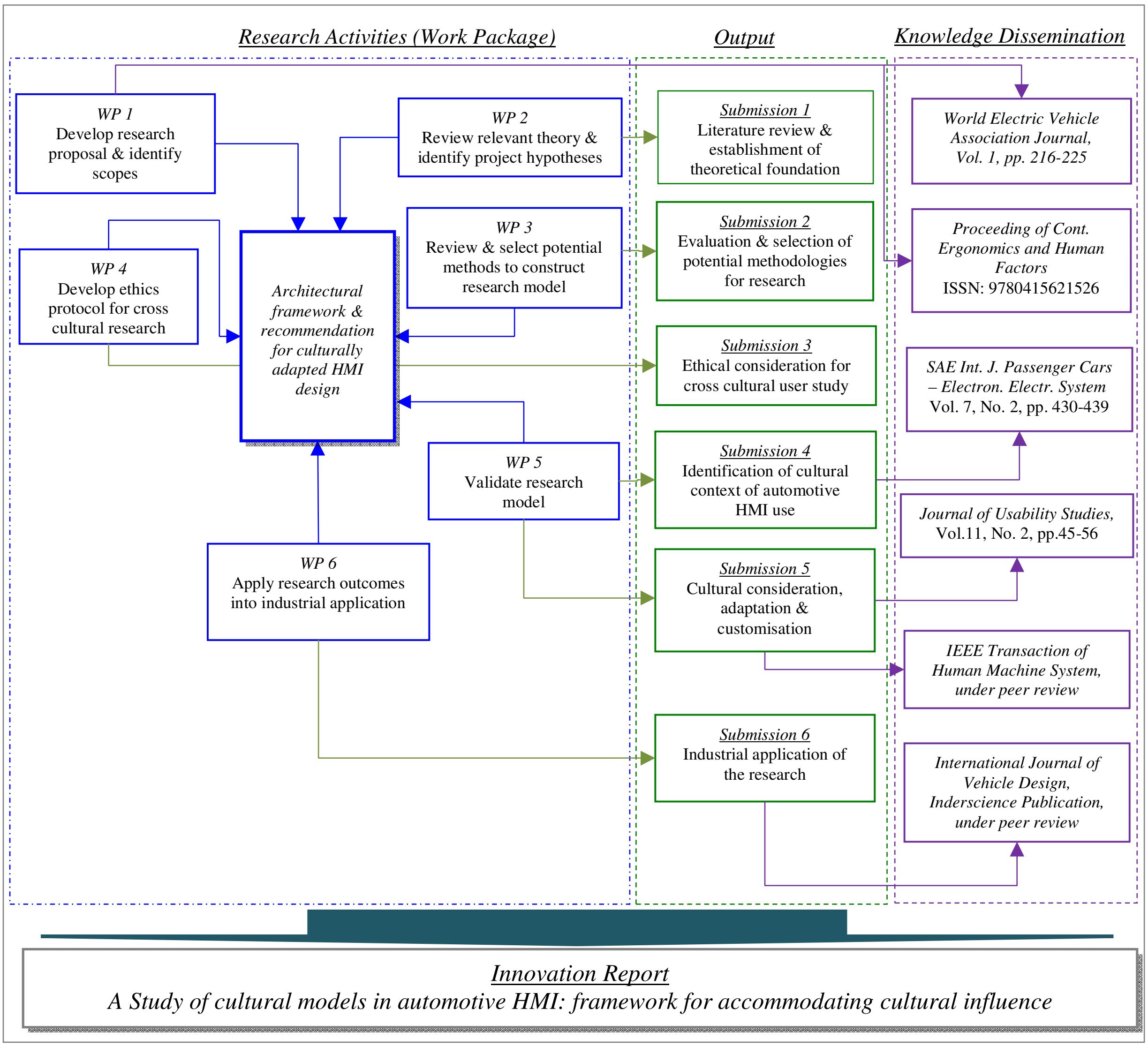


Figure 1: EngD submission portfolio

2 LITERATURE REVIEW

2.1 Chapter Overview

This chapter is concerned with the literature review of the research. The key aim of this chapter is to review related literature by identifying key studies to explain major issues and practical problems which lead to the identification of the methods this research intends to look at and to consider matters other researchers have considered important in order to answer the research question. The outcome of this study is to gain knowledge in the area of the specific objectives of the research outlined in Chapter 1 and define hypotheses to meet these objectives.

2.2 Introduction to Literature Review

The context of the research is an automotive display HMI and the issues, both general and specific, which pertain to the field and the effect of culture within it. This aim is achieved by addressing fourscore areas of theory:

- Technology development
- Cultural model
- Human Machine Interface (HMI)
- Usability

2.3 Technology Development

2.3.1 Definition of Technology Development

The term 'Technology Development' refers to a special class of development projects where the deliverable is new knowledge, new technology, a technical capability, or a technological platform (Cooper, 2007). These projects include fundamental research projects, science projects, basic research as well as technology platform projects that lead to multiple commercial projects or new product or new process development (Cooper, 2007). According to Leonard-Barton (1995), in a technology development project, user and technology evolve in a symbiotic way (Figure 2). In this research, user and technology have an interdependent relationship due to cultural influence; therefore, the bottom left to right quadrant of the figure is representative of this study phenomenon.

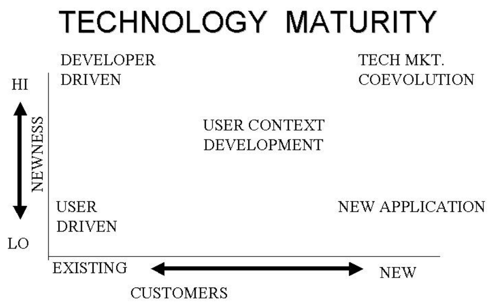


Figure 2: Technology Development Process
(*Leonard-Barton, 1995)*

2.3.2 Role of Customers in Technology Development

Understanding user needs and incorporating them into the new design is one of the most critical factors in new technology development (Cooper, 1979; Cooper & Kleinschmidt, 1987; Rothwell *et al*, 1974; Zirger & Maidique, 1990). To ascertain the importance, Narver & Slater (1990) and Slater & Narver (2000) argue that, in the market pull environment, companies must focus on the market they serve and operate.

Researchers have identified five important roles for the customer in value creation: resource, co-producer, buyer, user, and the product (Finch, 1999; Gersuny & Rosengren, 1973; Kaulio, 1998; Lengnick-Hall, 1996). Nambisan (2002) emphasised main three roles: customer as a resource, the customer as co-creator, and customer as a user. The first relates to the customer as a source of innovation, the second relates to customer participation in product design and development, and the third relates to customer involvement in product testing and product support.

2.3.3 Challenges Involving the Customer in Technology Development

While some researchers argue that customers need to play a pivotal role in the generation of new technology ideas, others argue, equally fervently, that involving customers in idea generation will simply lead to imitative, unimaginative products (Nambisan, 2002). Macdonald (1995) argues that being too close to customers or being 'customer-led' may prove detrimental to innovation and the organisation's performance. Table 2 defines some of the customer's involvement challenges defined by the authors according to literature review.

Table 2: Negative aspect of customer input in product or technology development

Root cause	*Reason*	*Validity of argument*
Customer input lacks credibility.	Difficult to predict final customer behaviour based on expressed attitudes towards a product.	Customers are changing their mind all the time (Brian, 2010). Therefore, in some cases, companies should ignore their customers (Martin, 1995).
	Received information is perceived as less credible and low quality.	Customer data collection is part of the marketer's responsibility. However, both marketing and product development professionals do not always consider each other's information to be credible (Song *et al*, 2009).
Customer input does not help create innovative product ideas.	An unclear method of listening "Voice Of the Customer (VOC)" can be problematic in PD.	Product developers are unsure what to ask customers (Ortt & Schoormans, 1993; Ottum & Moore, 1997).
	A lack proactive process for customer research hinders product or technology development progress.	Customer research methods which are focused on evaluation of products (Wind & Lilien, 1993), can be considered as reactive to product usage.
	Lack of new information from customer research does not help in product development organisation.	Customer research attempts to build on existing and already fulfilled needs ((Burton & Patterson, 1999), thus, information received from the market is not useful to radical innovation projects (Lynn *et al*, 1996).
Customer input lacks comprehensiveness.	Customer research is difficult to comprehend.	Marketing and R&D employees' use different technical terms during product development (Moenaert & Souder, 1990) and, they have difficulty understanding each other.

Although the customer may not always be able to express their wants, it is, however, important to understand, how they perceive products, how their needs are influenced and how they make product choices (Van K, 2006). In this way, it helps to avoid working on a new product that has a low probability of success in the first instance (Rochford, 1991). Research indicates that well-managed customer relations can moderate the effects of inadequate product performance (Priluck, 2003).

2.3.4 Customer Involving Method – Kano Model

The Kano model is an effective tool for understanding customer preferences due to its convenience in classifying customer needs based on survey data (Kano *et al*, 1984). It aims to connect the requirements fulfilled by products with customer satisfaction and identifies types of requirements that influence ultimate customer satisfaction. The Kano model has been applied to a wide variety of products and services including strategic thinking, business planning and product development (Watson, 2003). According to Kano, invisible ideas about user-defined quality can be made visible with a clear requirements classification (Berger *et al*, 1993). Kano *et al*, (1984) derive four needs categories in the requirements classification map as shown in Figure 3. The model captures the nonlinear relationship between product, performance and customer satisfaction (Xu *et al*, 2009) by classifying product attributes into four categories (Kano *et al*, 1984), described below.

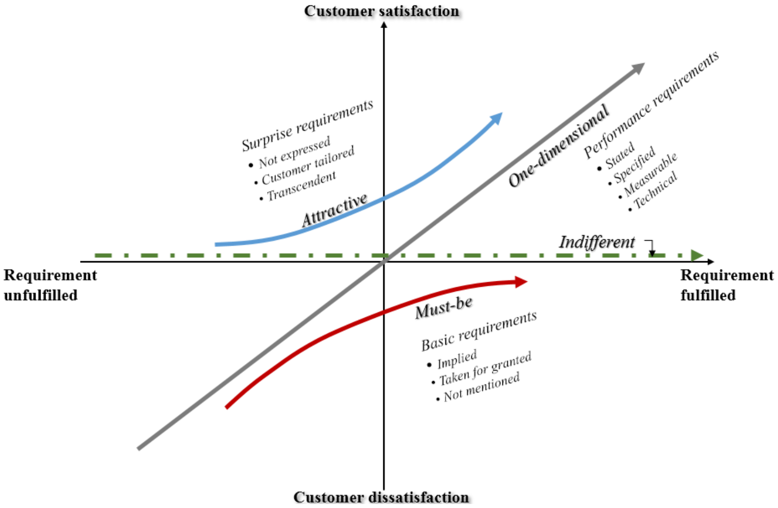


Figure 3: Kano Model of customer satisfaction
(Berger et al, 1993)

Must-be Requirements (M): Some requirements, whose presence adds no value but its absence affects customer satisfaction very negatively can be classified as 'Must-be' (Berger *et al*, 1993). As the customer takes these requirements for granted, i.e., requirements represents a fundamental customer need, their fulfilment will not increase satisfaction (Matzler & Hinterhuber, 1998).

Fulfilling the 'Must-be' requirements will only lead to a state of 'not dissatisfied' (Matzler & Hinterhuber, 1998).

One-dimensional Requirements (O): For some requirements, customer satisfaction can be proportional to the level of product functionality. Kano designates such customer requirements as 'One-dimensional' (Rejeb *et al*, 2008). 'One-dimensional' requirements are usually explicitly demanded by the customer (Matzler & Hinterhuber, 1998). Therefore, if these types of requirements are fulfilled, they can become a source of customer satisfaction.

Attractive Requirements (A): Requirements, whose presence adds value to the product but their absence has no negative impact, can be classified as 'Attractive' (Berger *et al*, 1993). 'Attractive' requirements are neither explicitly expressed nor expected by the customer; however, fulfilling these requirements leads to more than proportional satisfaction (Matzler & Hinterhuber, 1998). As such, even if they are not met, they will not cause any dissatisfaction (Matzler & Hinterhuber, 1998).

Indifferent Requirements (I): In certain cases the presence or absence of a requirement will make no difference to customer satisfaction, hence, if the requirement in question is of no importance to the customer it can be classified as 'Indifferent' (Berger *et al*, 1993). This indicates that the customer is not interested in the level of performance of the requirement (Xu *et al*, 2009).

2.3.5 Summary

This section discusses the first parent discipline defined in Section 2.2, 'Technology Development'. The literature review clearly suggests that understanding customer needs is the indicator of success in any innovative technology development project. While customers have critical roles in value creation, there are challenging aspects of customer input in technology development as can be seen from Table 2. Kano model of customer involvement method, discussed in Section 2.3.4 is used most frequently to uncover unmet consumer needs. This model has relevance to this research project and will be used to capture regional automotive user design preferences.

2.4 Cultural Model

2.4.1 Definition of Culture

Rice (1997) describes culture, as the values, attitudes, beliefs, ideas, artefacts and other meaningful symbols represented in the pattern of life adopted by people that help them interpret, evaluate and communicate as members of a society. Culture is also regarded as an umbrella term for aspects in life that influence our thinking (Hofstede, 1997). As such, it includes our technology and material artefacts-anything one would need to know how to become a functioning member of society (Geertz, 1973). These various definitions reflect some of the many attempts that have been made to understand how cultures differ amongst societies. Summing it up, Elzinga & Jamison (1981) define that the word culture has different meanings in different intellectual disciplines and systems of thought.

Stewart & Bennet (1991) divide culture into the objective culture and subjective culture. Objective culture is what humans make, and what they consciously transmit from generation to generation (Wurzel, 2005). Subjective culture refers to the psychological features of a culture, including basic assumptions, values, and patterns of thinking, which is expressed non-verbal or implicit. Subjective culture is difficult to examine because it operates outside of conscious awareness (Triandis, 1972; Bennett, 1998).

2.4.2 Description of Cultural Models

Many models operationalise culture and systematically divide it into measurable and comparable parts (Khan & Williams, 2014). Each of these models proposes a different way of understanding or qualifying the differences in culture. These cultural theories include the Pyramid Model (Hofstede, 1980), the Iceberg Model (Hoft, 1996), and the Onion Model (Trompenaars, 1993; 1994; 1996), all of which consider culture to be comprised of at least an outer surface layer (the directly observable aspects of culture) and a deeper, hidden layer (the intrinsic aspects of culture, outside immediate awareness) (Young *et al*, 2011). Of the several cultural models referenced in the literature, those of Hofstede are outlined in this section. Subsequently, dimensions defined in the model are compared with other approaches to unpack the concept of culture.

2.4.2.1 Hofstede's Cultural Model

Amongst all available cultural models, Hofstede's cultural dimensions constitute by far the most influential national cultural framework (Steenkamp, 2001). Sondergaard (1994) stated that, the research framework used by Hofstede is based on the rigorous design with systematic data collection and coherent theory. Hofstede's concepts were used to construct ideas about how the technology acceptance may be affected by culture (Straub *et al*, 1997). Several research studies were also constructed based on the Hofstede model; for example, Web interface (Marcus & Gould, 2000, 2015; Smith *et al*, 2004; Sheridan, 2003), Consumer behaviour analysis (Mooij & Hofstede, 2011; Dawar & Parker, 1994), Market research (Baumgartner & Steenkamp, 1999), New Product Development (Nakata & Sivakumar, 1996).

Several authors, however, criticised this cultural model. Hofstede's reliance on a sample of IBM employees in the 1960s and 1970s to draw conclusions about the wider cultures they live in is heavily critiqued. Hofstede, in his defence, states that he is not making an absolute measure, he is merely gauging differences between cultures and this style of cross-sectional analysis is appropriate (Hofstede, 1998). Other research has also found that culture is in fact fragmented across the group and national lines (DiMaggio, 1997). For example, the consideration of cross-border influences of Arabic cultures would take one to see the weakness (Straub *et al,* 2002). Hofstede, however, argues that national identities are the only means we have of measuring and identifying cultural differences (Hofstede, 1998). Despite all these criticisms and the possible shortcomings of his research Hofstede's work continues to be cited and used.

Based on elaborated research Hofstede developed five cultural dimensions that capture culture through scores on five values: 'Power Distance' (PDI), 'Individualism' vs. 'Collectivism' (IDV), 'Masculinity' vs. 'Femininity' (MAS), 'Uncertainty Avoidance' (UAI), and 'Long' vs. 'Short-Term Time Orientation' (LTO). The five dimensions of culture influencing a wide range of behaviours are summarised in Table 3.

Table 3: Five dimensions of Hofstede's cultural model
(Hofstede, 1984, 1991, 2001)

Cultural dimensions	*Definition*	*Characteristics*	*Example countries*
Power distance (PDI)	The extent to which the weaker members of a society accept inequality in power.	*High Power Distance*: Centralised decision making, management, and superiors are highly respected and have the last say in decisions. *Low Power Distance*: Everyone expects to share in decision making; management hierarchies are flatter and more open to questioning.	Germany, Austria and Scandinavian countries score low on this dimension.
Individualism / Collectivism (IDV)	Relationship between individuals and groups.	*High Individualism*: Social ties are loose, Individuals expected to look after themselves. *High Collectivism*: Individuals are strongly incorporated into groups of family, school; government policies often favour the group over individual rights.	Individualistic countries are Australia, Canada, US, UK, and Holland. Latin America countries are extremely Collectivistic countries.
Masculinity/ Femininity (MAS)	Distribution of emotional roles between genders.	*High Masculinity*: Favours assertiveness, Emphasis on the competition. *High Femininity*: Focuses on quality of life, Importance placed on the wellbeing of relationships.	Japan scores high on Masculinity; countries that score high on Femininity are Sweden and Norway.
Uncertainty Avoidance (UAI)	The extent to which a society feels threatened with unknown situations, ambiguity, and uncertainty.	*High Uncertainty Avoidance*: Strictly defined rules of behaviour and formality, Things that are different or unexplained can be viewed as dangerous. *Low Uncertainty Avoidance*: Willingness to take risks, more experimentation and / or innovative behaviour.	Countries that score high on this dimension are Latin countries; countries that score low are Denmark, Sweden, and Singapore.
Long/Short-Term Orientation (LTO)	The extent to which members of a cultural group are willing to accept delayed gratification of material, social and emotional needs.	*Long-Term Time Orientation*: Promotes virtue and persistence, Focus towards future rewards. *Short-Term Time Orientation*: Emphasises the past and present, Fosters a respect for tradition.	Philippines, Nigeria, and Pakistan display low on Long-Term Orientation index.

2.4.2.2 Comparison of Available Cultural Models

Table 4 illustrates a comparison between four of the most popular cultural models of Hofstede, Trompenaars, Globe and Hall. While Hall and Hofstede cover similar industrial categories, Hall surveyed only three countries. The Trompenaars and Globe model also cover less homogeneity compared to Hofstede. Their field of study covers service management as opposed to product and technology management. Therefore, comparing these, the cultural model of Hofstede is more representative and homogeneous. He analyses data from a single multinational company and its 54 regional subsidiaries to conclude his pioneering work of national cultures (Shi, 2011).

Table 4: Comparisons of cultural models

Research basis	*Hofstede Model*	*Trompenaars Model*	*Globe Model*	*Hall Model*
Reference	Hofstede, (1984, 1991, 1998, 2001)	Trompenaar, (1993, 1994, 1996)	House *et al*, (2004)	Hall, (1990)
Type of participants	Software engineers, Information technology engineers, pilots, civil service managers	Business managers	Product managers	Information technology engineers
Type of organisations	Multi-national	Multi-national	No multi-national	No multi-national
Type of industries	Information technology	Services industry	Food processing, Financial services	Information technology
Number of countries surveyed	72	50	62	3
Number of dimensions	5	7	9	4

2.4.3 Summary

This section describes 'Cultural Model' in greater details. Existing literature has been reviewed and the requirements for cultural data analysis have been specified. The literature review provides general justification for the use of Hofstede's cultural dimensions to make comparisons among cultural groups. In support of the theoretical relevance of Hofstede's framework, the dimensions are conceptually sound, grounded in the literature, and empirically validated. Another attractive feature of his framework is that, in addition to providing an approach to classify and compare cultures, it is useful in formulating hypotheses for comparative cross-cultural studies. This study considers national cultures as a context and source of differences in how people relate to, works with, and come to understand and communicate their preferences in UI systems (Khan *et al*, 2016). As such, Hofstede's VSM08 (Value Survey Module 2008) is selected as the questionnaire with which to measure cultural differences. VSM scores capture societal differences in a robust manner and have proved useful in cross-national market research. Unfortunately, no such survey module exists with other models to make comparisons among cultural groups. The literature review also guided other models that are used in various researches.

2.5 Human Machine Interface (HMI)

2.5.1 Definition of HMI

Moran (1981) defines HMI as, those aspects of the system that the user comes in contact with, which in turn means an input language for the user, an output language for the machine, and a protocol for interaction. Baumann & Lanz (1998) also describe HMI as the part of an electronic or device which serves as the information exchange between the operator/user and the machine/device.

As described in Section 1.2.1, a typical HMI system (Figure 4) in a vehicle environment is described as, a) Primary driving controls (e.g., steering wheel, radio buttons, brake pedal, etc.); b) Driver information center (e.g., instrument cluster); c) Displays/controls associated with supporting the primary driving task (e.g., GPS Navigation); d) Supplementary displays associated with the primary driving task (Just-auto, 2010). A restrictive means of definition proposed by the European Commission, DG XIII under project code TR1103 describes the HMI concept as related to the interaction of a user with a technical system in order to perform a task that the system supports by, 1) taking on charge part or all the control of the process. In this case, the user becomes a supervisor, at least for part of the task: examples in the automotive field include the automotive gearbox or adaptive cruise control; 2) Informing the user about the status of the system or about events which can influence the performance of the task, as the tachometer in speed control or a GPS Navigation route guidance system; and 3) Multiplying the inputs given by the user as in the power steering (Sommerville, 1998). In summary, Vehicle HMI in this research can be roughly categorised into two systems, (1) user input system; (2) presentation of feedback and driver information. These two systems are supported by various information, multimedia, connectivity, communication and driving safety technologies.

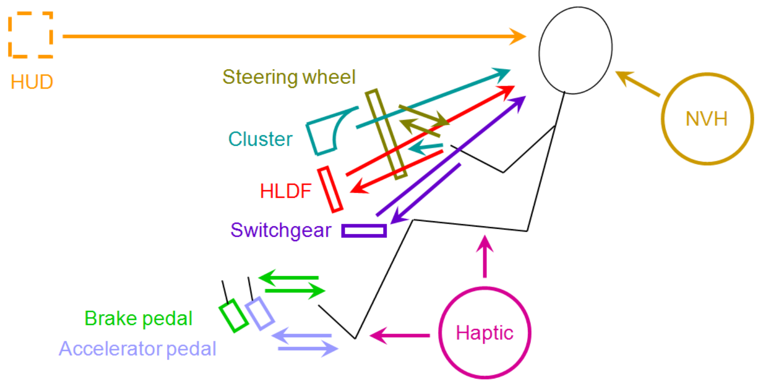


Figure 4: Typical HMI system in a vehicle

2.5.2 Overview of HMI Architecture

The HMI system utilises two main user-related domains, User Control (UC) and User Interface (UI). The user control is the part of the software that takes instruction from the user. The user interface uses Graphical User Interface (GUI) software to provide a visual search for the required information and UI tasks. Overall HMI architecture consists of two software parts: An input language and an output language (Foley *et al,* 1990). The user utilises the input language to communicate with the machines by manipulating interaction devices such as buttons, keypad or touchscreen. The machine uses the output language to communicate its state to the user. The output graphical language is pixels which build more complex elements such as lines, boxes, letters, icons, symbol, etc. According to Foley *et al,* (1990), the main goals of display HMI are: 1) Increase speed of learning; 2) Increase speed of use; 3) Reduce error rate; 4) Encourage rapid recall; 5) Increase attractiveness.

2.5.3 Influence of Culture in HMI

Previous studies report several issues associated with culture and HMI design. For example, in HMI design, colour plays a vital role due to the sheer aesthetic aspect; however, it also indicates intercultural differences because colours carry additional information and meaning (Rossger, 2014). The Colour-Culture Chart in Table 5 illustrates some of the different meanings (Rossger, 2014; Boor & Russo, 1993), the designer is confronted with. Colour may also influence the user's expectations about display navigation style and content, as well as overall satisfaction (Barber & Badre, 1998).

Table 5: Meaning of colours in different cultures
(Adapted from Boor & Russo, 1993; Rossger, 2014)

Colour	*Regional Culture*				
	China	*Japan*	*Germany*	*USA*	*India*
Red	Happiness	Anger	Anger	Danger	Energy
	Power	Danger	Danger	Stop	Wedding
Yellow	Birth	Grace		Cowardice	God
	Wealth	Nobility		Temporary	Sickness
White	Death	Death	Purity	Purity	Truth
	Purity		Cleanness	Luxury	Peace
					Death
Black	Party		Luxury	Death	Sin
	Money		Death	Style	Anger
Green	Dynasty	Future	Nature	Nature	Sympathy
	Ming	Youth	Environment	Safety	Religion

The spatial orientation of presenting information, including vertical input and reading by the regional user has implications for HMI usability; for example, Middle Eastern cultures in Arabic and Hebrew have orienting text, from right-to-left, as opposed to left-to-right in the rest of the world (Barber & Badre, 1998). Thus, the left side of a display screen might be the first focus of attention for American users; however, the right side would be the initial focus for Middle Eastern users (Barber & Badre, 1998). Another problematic example of metaphors includes turning to the next page or display screen while Western users turn to the next page from right-to-left, Arabic users carry out the opposite, i.e., left-to-right. There are other issues associated with culture and interface design such as icon recognition. Culture is an important factor in how people understand the icons and images used in interface design (Evers *et al*, 2000). A particular source of irritation may be the selection of gestures as a basis for icons. Gestures have an extremely culture driven context (Verstand, 2011; Ege, 2014). Also, symbols such as stars or crosses have a strictly cultural connotation (Rossger, 2014).

2.5.4 Influence of Culture in User Cognition

Ito & Nakakaoji (1996) propose a two-mode model for the interaction of users with a visual information system in a cognitive process. They define the first mode as the 'Listening Mode'. In this initial mode, the user receives perceptual information, becomes aware of what is happening on the screen, and then associates the perceived information with semantic meanings and, finally, reasons about the presented information. In the second mode, the 'Speaking Mode', users provide information back to the computer. The initial listening mode is known in HCI as affordance perceptions. Once users have understood the information being presented they enter the phases of applicability check, enactment with expectations and confirmation. Ito &

Nakakaoji (1996) argue that culture affects all phases of the listening and speaking modes, but has the least influence in the listening mode (affordance perception) of interaction (Figure 5).

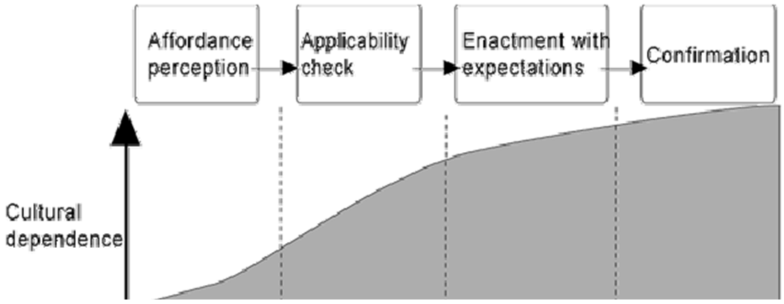


Figure 5: Levels of cultural dependence in interaction
(Ito & Nakakaoji, 1996)

2.5.5 Frameworks for Cultural Influence Integration

2.5.5.1 Marcus and Gould UI Guidelines

An influential approach to integrate cultural influence into the interface design by HCI researchers has advocated the mapping of Hofstede's cultural dimensions to UI components (Marcus, 1996, 2001; Marcus & Gould 2000, 2015). They developed characteristic factors of UI and gave examples that can effect on UI design. The recommended guidelines are summarised in Table 6. The guidelines serve as a framework for determining how cultural differences can influence components of the UI design and are, therefore, used within this research to evaluate regional drivers' preferences in design requirements and the development of culturally adapted automotive HMI solution.

Table 6: HCI recommended guidelines for cross-cultural user interface
(Adapted from Marcus & Gould, 2000; 2015)

Cultural dimension	*Classification*	*User Interface guidelines*
Power Distance (PDI)	High	Highly structured access to information, strong focus on authority, experts, certification and official stamps, the importance of security and restrictions or barriers to access.
	Low	Less highly structured access to information, less importance on information access, transparent, integrated, implicit freedom to roam.
Masculinity vs. Femininity (MAS)	Masculine	Quick results for limited tasks; navigation oriented for exploration and control, graphics, sound, and animations for user attention, explicit distinction between gender and age.
	Feminine	Interfaces should use aesthetic appeal and poetry as a way of gaining users' attention; support mutual cooperation and exchange of ideas and support.
Individualism vs. Collectivism (IDV)	Individualist	Content focuses on personal achievement and contains or encourages personal opinions; uses images of materialism and consumerism to denote success, emphasis on what is new.
	Collectivist	Content focuses on group achievement and official slogans while discouraging personal opinions, emphasis on tradition and history.
Uncertainty Avoidance (UAI)	High	Minimal menu options, simple and descriptive help facilities, navigation structure focuses on preventing users from getting lost, restricted amount of data, emphasis on redundant cues such as colour, typography, sound, etc., to reduce ambiguity.
	Low	Many menu options; colours and images to provide additional information, however, less control on navigation, complexity with content, structure and choices.
Time Orientation (LTO)	Short Term	Navigation style should be simple and allow users to complete tasks quickly. Rules should be used to verify the credibility of information and information content.
	Long term	Navigation style and content can be more complex as users will persevere until they gain an understanding, content focused on practice and practical value.

2.5.5.2 Other Frameworks

Cultural Fingerprint

Smith *et al*, (2004) proposed a design approach using "cultural fingerprint" of a culture. According to this approach, the fingerprint is a way of using Hofstede's Value Survey Module (VSM) scores for each country to map out where a particular country sits in the four-dimensional space of: 'Individualism', 'Masculinity', 'Power Distance' and 'Uncertainty Avoidance'. This fingerprint can be mapped into the "cultural fingerprint" of existing sites or proposed site that is designed for the culture. A "cultural fingerprint" would be calculated by a team of expert evaluators. By comparing the two fingerprints, a design team can evaluate whether a misfit exists and, if it exists, then where the misfit between the target culture and the site design exist (Smith *et al*, 2004).

Cultural User Interface (CUI)

A CUI is a user interface that is intuitive to a particular culture (Yeo, 1996). The CUI can be created for a culture to take advantage of the knowledge of the target culture and incorporates country boundaries, its language, cultural conventions and shared activities (Yeo, 1996). CUIs are developed collaboratively with target cultures, thus, the problems associated with localisation such as misinterpretation of elements in the CUIs, are unlikely to occur (Yeo, 1996). Yeo also suggests that experts of the target culture should actively participate to decide what sort of elements will go into the CUI design and the applications within the design must be separated into functional components and user interface components.

Other researchers propose a more general framework to seek a better way to understand the effects of culture on usability and user interaction (e.g., Ford & Kotzé, 2005a, 2005b; Xinyuan, 2005). Their model identifies five general categories of variables that can influence usability. These are 1) subjective culture; 2) the interface; 3) user acceptance; 4) speed of performance; 5) objective culture.

2.5.6 Summary

This section presented a detailed review of Human Machine Interface. The definition of vehicle HMI, its role in automotive industries and overview of the architectural patterns are discussed. The available methodologies and framework to deal with cultural influence in UI design, particularly by HCI practitioners have also been reviewed and some provisional candidates have been selected.

The literature review suggests that the interest in cultural models by the various design communities, especially HCI designers, has increased since Marcus & Gould (2000; 2015) derived UI guidelines directly from Hofstede cultural dimensions. Their recommended guidelines serve as a framework for determining how cultural differences can influence the components of user interface design and will, therefore, be used in the current study as a means to test the differences in drivers' preferences in automotive HMI design requirements.

2.6 Usability

2.6.1 Definition of Usability

The term 'usability' originates from HCI, originally being used in reference to visual displays. Within the context of an automotive HMI, usability, can be defined as a construct comprising a driver's perception of the HMI system's 'Usefulness', 'Ease of use', 'Ease of learning', and user 'Satisfaction', combined with the actual effectiveness and efficiency of the system as a whole (Wallace & Yu, 2009). The original term usability has evolved over several decades. In recent days, the most common definition of usability has been given by the standard ISO 9241-11, (1998), which defines it as the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". Thus, usability is an essential part of ergonomics, which permits humans to use machines and tools efficiently, effectively and in a way that is satisfying (Sarodnick & Brau, 2006). Wallace & Yu, (2009) stated that to measure and compare the usability of a system across two cultures, effectiveness, efficiency, and user satisfaction factors must be measured and compared.

2.6.2 Components of Usability

Jordan (1998) proposed a five-component model of usability.

Guessability **–** a measure in terms of the cost to the user when using a system to perform a new task for the first time. Jordan (1998) argued that lower cost (in terms of time on task or errors made by the user) will increase the 'Guessability'. He also stated that 'Guessability' is important for products that have one-off users (for example, fire alarms, door handles etc.).

Learnability **–** a measure which specified users can achieve a competent level of performance on specified tasks with a system, "having already completed those tasks once previously" (Jordan, 1998; p13). This argument is supported by Sauro (2013): user task performance improves after repeated trials, thus more practice results in less time needed to complete tasks. A more learnable system is one that reduces the time it takes to complete tasks as users spend more time with a system, faster than others. Previous HCI study corroborates the consideration of repeated exposure to improve user task performance with UI systems (Ehret, 2002).

Experienced User Performance (EUP) **–** refers to the relatively unchanging performance of a user who used a system several times before performing specified tasks. EUP is important for a stable system where changes occur over a long period of time and system operation has been learned to achieve a high-level task performance (e.g., complex software tool) (Jordan, 1998).

System Potential **–** refers to the optimum level of effectiveness, efficiency, and satisfaction that has been gained by a user to complete tasks with a system.

Re-usability **–** refers to the user ability to complete specified tasks with a system after 'comparatively long period of time' away from these tasks. Jordan (1998) clarified that 'comparatively long period of time' does not refer to a "time away" from a complete system, but "merely a particular task" (p15) for which the system can be used.

Nielsen (1993) also defined five factors (Learnability, Efficiency, Memorability, Errors and Satisfaction) that can be translated to usability. Amongst these factors, the definition of 'Learnability' (The system should be easy to understand such that the user can begin using it without delay) and 'Memorability' (The user should be able to return to the system after a period of non-use without having to re-learn large numbers of functions) has similarity with Jordan's five-component usability model.

2.6.3 Usability Measures

According to ISO 9241-11, usability can be measured in three aspects: 'Effectiveness', 'Efficiency', and 'Satisfaction' (Section 1.4.2 defines the definition of Satisfaction).

Effectiveness: is defined as the extent to which a task is achieved (Jordan, 1998). Thus, effectiveness measurement is tied to the issue of user task completion: "the extent to which a goal or task is achieved" (Jordan, 1998; p18). According to Jordan, effectiveness can be a "black or white" issue (p19). Therefore, for the purpose of this study, effectiveness will be measured based on successful completion of an HMI task by the participants.

Efficiency: is tied to task performance (error rate, time on task, attempt, etc.): "the amount of effort required to accomplish a goal" (Jordan 1998, p20) or task. Jordan stated that a high efficient task requires less effort, as such in this study efficiency can be measured based on the number of attempts on a given task by participants.

Error rate along with time on task are the most widely used measures of usability (Jordan, 1998). Jordan defines four types of errors:

Slips: refers to mistakes that occur "when the user has an erroneous model of how product works" (p20).

Minor error: refers to one which user can notice and rectify instantly.

Major error: refers to one which user can rectify, but with less efficiency and greater costs in terms of time and annoyance.

Fatal error: refers to one which prevents the user from completing the task he/she has attempted.

2.6.4 Usability Testing

Usability testing focuses on user needs and uses empirical measurement and iterative design (Nielsen, 1994). Usability testing typically involves measuring users' performance on typical performance tasks, noting the frequency and type of errors made and recording task completion time (Pitts, 2011). Usability testing aims to achieve the following five goals: 1) Improve the intended system usability; 2) Involve real users in the testing; 3) Give the users' real tasks to accomplish; 3) Enable test engineer to observe and record the actions of participants; 4) Enable test engineer to analyse the data obtained and make changes accordingly (Dumas & Redish, 1993). According to Shneiderman (1987), the usability tests require users to perform defined tasks in a typical task environment so that the following data can be collected:

- Time for users to learn a specific function.
- Speed of task performance.
- Type and rate of errors by users.
- User retention of commands over time.
- Subjective user satisfaction.

2.6.5 Relationship between Culture and Usability

Research on usability has helped describe much about the relationship between culture and usability (Wallace & Yu, 2009). For example, it has been shown that websites in computer-mediated communication domains vary across cultures and are based on culturally-specific characteristics, or cultural markers (Singh, 2003). These differences are theorised using Hofstede's (1980; 1884; 1986; 1991) national cultural dimensions. Badre, (2000) concludes that users' preferences for a website are affected by the cultural features. This conclusion is supported by Kelsey & Amant, (2008), who found that users from different cultural backgrounds are likely to use a website for different purposes. In addition, the use of translation in a multilingual website (even when done expertly) affects user satisfaction (Nantel & Glaser, 2008), as does the use of culturally familiar or unfamiliar icons (Shen *et al,* 2006) in software applications. In a more comprehensive study of usability and culture, Evers & Day (1997) found culture to be an important factor regarding the interrelationships of perceptions of efficiency, effectiveness, satisfaction, and user behaviour when using a software application. In short, culture is likely to influence many usability aspects of a product or system.

2.6.6 Summary

This section discussed usability as a means of understanding user experience. The main objective was to define usability in terms of a 'usable' system or product, understand its components and methodologies to plan for system usability testing. This research is grounded in the belief that culture is a variable concerning the user attitude towards usability. As such relationship between culture and usability is investigated to understand cultural diversity of users in technology challenges for usability testing. It is clear that there is a relationship between culture and UI system due to usability. This, in turn, influences underlying technology usage, which accommodates the UI system.

The literature review provided knowledge about usability component model. With this knowledge, future culturally adapted HMI solution will be designed in a way that is easier for Indian participants to understand and using it without any delay during their driving. As such, 'learnability' will be emphasised and examined in this research.

2.7 Research Hypotheses

The review of literature learning leads to the development of several hypotheses that relate to the research objectives defined in Section 1.4. Table 7 derives all of these hypotheses that will be examined during this research.

Table 7: Research Hypotheses for the Study

Objective	*Hypothesis*
1:To investigate whether there are any differences in cultural values and orientation across automotive users from cultural groups.	***H1:*** There are significant differences in cultural values and orientation between the two cultural groups (the UK and Indian) who use automotive Human Machine Interfaces.
2:To investigate whether there are any differences exist during the use of an HMI system amongst users from cultural groups.	***H2:*** There is a correlation between automotive users' cultural values and HMI usability performances amongst cultural groups (India and the UK). ***H3:*** There are significant differences in HMI usability and task performances amongst UK and Indian cultural groups during the use of a vehicle HMI system.
3:To investigate whether there are any differences in automotive HMI design needs and preferences across automotive users from cultural groups.	***H4:*** There are significant differences in preferences for user interface attributes and features between UK and Indian users.
4: To assess what can be learned from cultural theories and methodologies derived by HCI practitioners that will help in the design of automotive HMI solutions.	***H5:*** A culturally generated user interface approach mapped into Hofstede cultural dimensions can be applied as a user requirement capture framework for automotive HMI design.
5: To evaluate whether culturally generated research findings will help automotive manufacturers to implement cross-cultural automotive HMI design processes and solutions.	***H6:*** The research findings will facilitate the development of culturally adapted HMI solution to measure automotive users' usability and task efficiencies.
6: To evaluate whether culturally adapted automotive HMI solutions have greater success in automotive HMI users' acceptance compared to non-adapted solutions.	***H7:***Indian automotive users' will exhibit higher levels of satisfaction towards a culturally adapted HMI solution once they are used to the system compared to the non-adapted solution.

2.8 Chapter Summary

This chapter, through literature review, has built a sound theoretical foundation upon which the research can be used. The research theory was derived from the research problem and research question. This chapter introduced research hypotheses based on the outcome of the literature review (Section 2.7). Each of the hypotheses will be examined in subsequent research phases. A research methodology will now be developed to be able to address the gaps in knowledge so that the current theoretical foundation can be built upon to be able to answer the research problems posed in this study.

3 RESEARCH METHODOLOGY

3.1 Chapter Overview

This chapter deals with the evaluation and selection of potential methodologies to develop a research design. The suitability of methodology for the design is based on several key requirements. The first requirement is that the methodology chosen should enable the construction of culturally adapted solution architecture and development approach based on the gathered and analysed data in Chapter 2. Secondly, the methodology chosen should enable enough flexibility to incorporate the existing best practices from the HCI and cross-cultural theories. Thirdly, the selection of a methodology should enable the construction of a research model which can contribute to cultural influences that are present in automotive HMI use cases. This requires a thorough research methodology study into existing paradigms of several theoretical areas used in cross-cultural and development research. Therefore, in this chapter, an outline of the research model, selected research methodologies, measurement techniques and data collection procedures are discussed to develop overall research design for the project.

3.2 Research Model

During the review of literature in Chapter 2, several models were analysed to help focus research, and outline ideas on how the research question can be answered. The first of these models is 'Kano model', illustrated in Figure 3: is a requirement capture tool to meet customer needs. The second of these models is 'Hofstede cultural dimensions' in Table 3: is a proven model for user cultural value comparison. The third of these models is 'Marcus & Gould (2000; 2015) web interface guidelines' in Table 6: illustrates how cultural dimensions are used to guide design requirements in HCI. Using these models, a representative research model can now be formulated to test the hypotheses derived in Section 2.7. This model is illustrated in Figure 6.

The underlying goal of the research model is to search for similarity and variation amongst selected cultural groups. The model incorporates the cultural, UI know-how and demographic variables as well as ethical factors as an input. The requirements of the sample selection criteria as well as design and user requirements feed into the evaluation environment and determine independent variables of the research model. The outputs of the evaluation and survey are the measurement of user cultural values, his/her performance of the use of the automotive HMI system, learnability and his/her preferences for the design features.

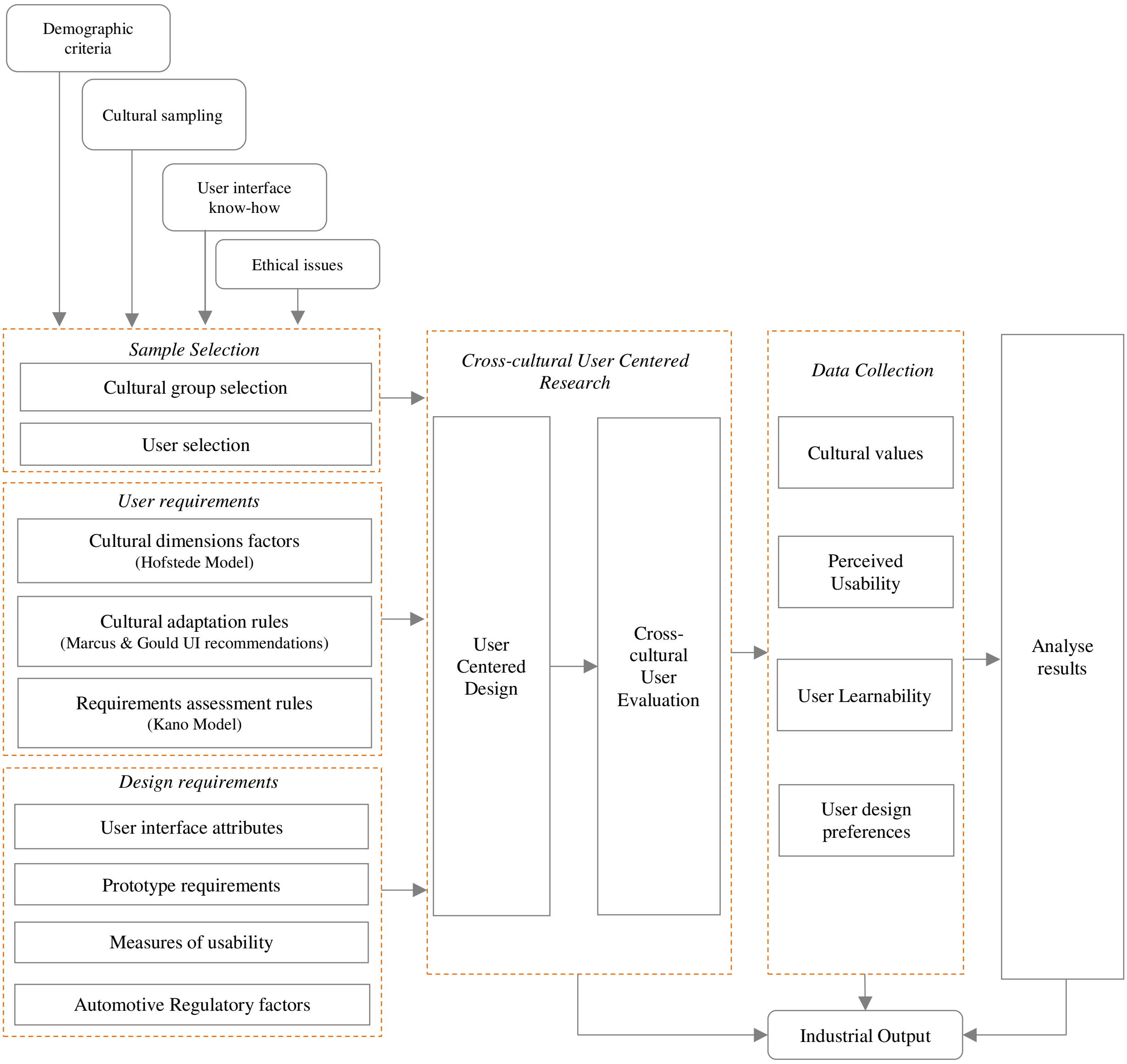


Figure 6: Research model

3.2.1 Research Outlines

Figure 7 illustrates the outline of the research design. In line with the defined research objectives (Chapter 1), hypotheses (Chapter 2) and research model, the evaluation methodology was tested using a development type process that synchronised with cross-cultural research and user-centered HMI evaluation studies. Specific research hypotheses were examined in each study (Study I, Study II and Application Study). The output from the first study (Study I) was used to refine the concept of the second study (Study II). The findings from both studies contribute to the final output of the research: an optimised HMI design framework containing architectural and feature design recommendation to deal with cultural requirements. The final stage includes an industrial application of a candidate in-vehicle HMI solution development using the developed architecture.

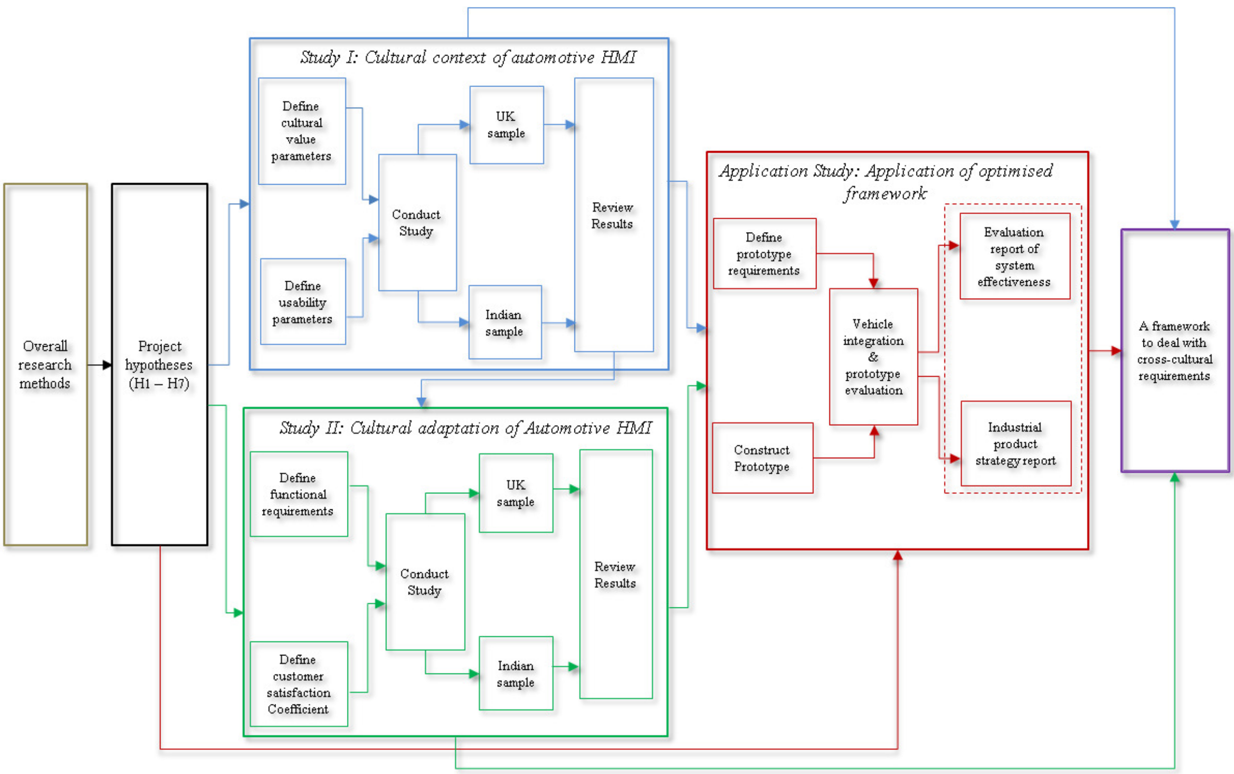


Figure 7: Research design

3.3 Methodology Selection

3.3.1 Use of Cross-Cultural Research

Cross-cultural research is a scientific method of comparative study which focuses on systematic comparisons amongst cultures and explicitly aims to answer questions about the incident, distributions, and causes of cultural variation (Ilessanmi, 2009). Results of cross-cultural research help researchers to make statements about the similarities and differences of cultures and to identify what may be universal and variable about human cultures, as well as to discover the reasons why the variation exists (Ilessanmi, 2009). Thus, given that the primary emphasis of this project is to analyse the influence of culture, the cross-cultural method is appropriate for the study.

Craig & Douglas (2000) identify three types of cross-cultural research approach. Descriptive research includes studies conducted in a single country with the purpose of understanding behaviour and marketing environments. Theoretical research includes research developed with the purpose of examining the applicability and generalisability of theories, models, and constructs that need to be developed in a different cultural setting. Finally, Comparative research refers to studies conducted in two or more countries with the purpose of comparing consumer or organisational behaviour. This study fits into the Comparative research category. This approach calls for a greater emphasis on the examination of hypotheses on studies of cross-cultural user experience with automotive HMI technology and the development of research instruments to test those hypotheses. The cross-cultural research process is circular in nature with built-in evaluation mechanisms at each stage of the process, which may cause the researcher(s) to re-evaluate decisions made at previous stages (Ilessanmi, 2009). Two types of methods can be used to execute cross-cultural research: 'cross-sectional' study or 'longitudinal' study. This research falls within 'cross-sectional' study. The study aims to underpin the differences of interest and preferences, however, ensuring that demographic variables, educational background, automotive driving and technology experiences are similar between selected cultural groups.

3.3.2 Use of Development Research

Development research (DR), has a dual focus, it develops practical and innovative ways of solving real time problems and proposes general design principles to inform future decisions (de Villiers, 2005). It aims to provide a relevant foundation to guide practice by generating design principles and methods that are both theoretically underpinned and empirically tested (de Villiers, 2005). The core principles of DR are based on iterative analysis, design, development, implementation and formative evaluation, which feed into a process of evolutionary prototyping (Reeves, 2000; Plomp, 2002). Figure 8 depicts the high-level process of a development research model. The proposed research aims to solve a real-time problem with the goal of developing design recommendations for future HMI development. Therefore, it falls under the DR category.

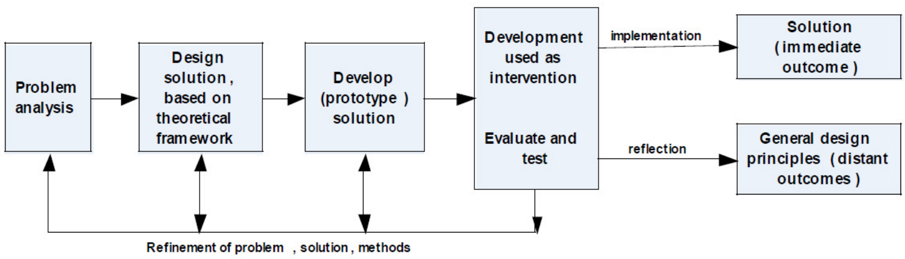


Figure 8: Development research model
(de Villiers, 2005; Plomp, 2002; Reeves 2000)

3.3.3 Use of User Centered Design

ISO 9241-210 (2010) defines User Centered Design (UCD) as an "approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques". Norman (1988) recognises the needs and interests of the user and focuses on the usability of the design, thus placing the user at the center of the design. He also recommends that the role of the designer should be to facilitate the task for the user and to make sure that the user is able to make use of the system as intended and with a minimum effort to learn how to use it. As such, usability is the desired outcome of 'User Centered Design'. This research encompasses studying users and evaluating usability, consequently, this project is influenced by UCD philosophies.

3.3.4 Experimental Design

In this study, the cultural group (Section 3.4.1) and automotive HMI display features under user test form the independent variables, while the Hofstede Value Survey Module-VSM08 (Section 3.4.6.1), Usability responses (Section 3.4.6.2) and Kano questionnaire responses (Section 3.4.6.3) form the dependent variables. Demographic and user experiences with UI technology are treated as extraneous variables. As the evaluation of user HMI task performance and preferences with HMI research seeks to measure individuals' responses to the design features under test, it is important that all participants from each group experienced the full range of HMI features. To achieve this, a mixed experiment design was employed with cultural group as a between-subjects factor and HMI tasks a within-subjects factor. The associated data and their relationship are defined in Table 8. The indicators consist of both objective and subjective measures. The objective measures are related to task performance and was measured using software and hardware prototype during experiments. The subjective measurement is recorded using a questionnaire, designed in accordance with the findings of the literature and administered after each evaluation. In order to measure the accuracy of subjective data, rating scales are used during experimentation.

Table 8: Relationship of dependent variables

Concept	*Indicators*	*Information required*	*Variables*
User performance (objective measures)	Ability to perform HMI tasks	Time taken to perform HMI tasks	Task completion time
		Number of errors made during a task completion	No of errors
		Number of completed tasks	No of successful tasks
	Task load	Perceived difficulty of task	No of attempts to complete a task
User preference (Subjective measures)	Acceptance of the HMI features	Liking of features	Kano rating CS Coefficient
	Attitude towards HMI features	Perceived usefulness Perceived ease of use Perceived ease of learning Perceived satisfaction	Usability rating

3.3.5 Summary

In this section, methodology selection issues pertaining to the research have been introduced. An overview of the research model is presented, illustrating the iterative approach to proving the evaluation methodology. This research centres on the use of a technology solution and evaluates cross-regional users' behaviour in an automotive scenario; therefore, it is important to replicate the context and workload demands of driving when undertaking the evaluation. Ideally, this requires a real-time vehicle driving approach in two different regions. However, the costs of real-time field study can be an expensive and challenging due to road traffic conditions in target countries. Also, the difference in traffic regulation means user task replication to achieve the same result is difficult. To overcome this challenge this project utilises a method of a stationary vehicle driving experimentation in a laboratory environment, with participants undertaking secondary user interface tasks using HMI screen and tactile buttons. This type of mixed methods and approaches offers advantages over real-vehicle driving studies with regard to repeatability, safety and efficiency as well as data collection and analysis process.

3.4 Measurement and Data Collection

3.4.1 Cultural Sample Selection

The focus of this study is the Hofstede's cultural dimensions and evaluating user cultural values within these dimensions. Therefore, to improve reliability while enhancing generalisability, a set of countries offering similarities across a number of aspects while being as far apart as possible on the theoretical dimension of concern, should be chosen (Alden *et al,* 1993; Sivakumar & Nakata, 2001). Thus, two countries were selected: India and the UK. According to Hofstede (2015), these countries have similarities within some cultural dimensions, however, most dimensions show profile differences.

3.4.2 Use of Students as a Sampling of Subjects for the Studies

'Student' use is a widespread practice in academic research, particularly in the area of cross-national research (e.g., Durvasula *et al,* 1993; Steenkamp & Baumgartner, 1995; Lysonski *et al*, 1996; Baumgartner & Steenkamp, 1996; Lee & Ulgado, 1997; Mitra *et al,* 1999; Ratner & Kahn, 2002; Choi & Lee, 2003). The advantage of using students as a sample includes low cost, availability, cooperation, and ease of following instructions (Hampton, 1979), which supports their use as surrogates for other populations (Khera & Benson, 1970; Yavas, 1994). Thus, given, a) the cross-national nature of the study, implying the need for matched samples; b) the objectives of the study in terms of hypothesis testing; c) the constraints of this study in terms of timing and budget, it was believed that using a sample of students in two locations is an adequate solution, allowing for the necessary control of all variables. This policy is adopted for the study I and II (Figure 7). In Application study phases, technical specialists are recruited to conduct user evaluation.

3.4.3 Sample Design Specification

The following basic requirements for participant selection are identified in all studies:

1. Native local UK and Indian residents who have lived in-country and the local region for between one and three years.
2. Aware of driving rules of their respective region and have a minimum of 12 months driving experience.
3. Experience with automotive HMI and consumer electronics UI systems.
4. Age range between 20 and 45 years (Participants from both genders and varied ages were included).

Point 1 helped to ensure that the participants had not been overexposed to foreign cultures, which may affect their technology user behaviour. Additionally, overexposure to foreign cultures may affect the technology acceptance behaviour of the research participants. Participants from both genders and varied ages were included.

3.4.4 Data Collection Procedures

The procedure for the evaluation studies is illustrated in Figure 9. All studies that are defined in Section 3.2.1 follow a similar procedure. This generic process is designed to adapt to the specific requirements of the study undertaken; for example, the type of task training and the number of evaluation conditions varies depending on the study objective and technology variable that required testing. Also, depending on the type of test, tasks explanation or task definition was different; for example, when implementing a usability test, the tasks explanation was minimal in order to learn from the user behaviour and task performance. The specific conditions for each of the research studies are described in the next chapters (Chapter 4, 5 and 6).

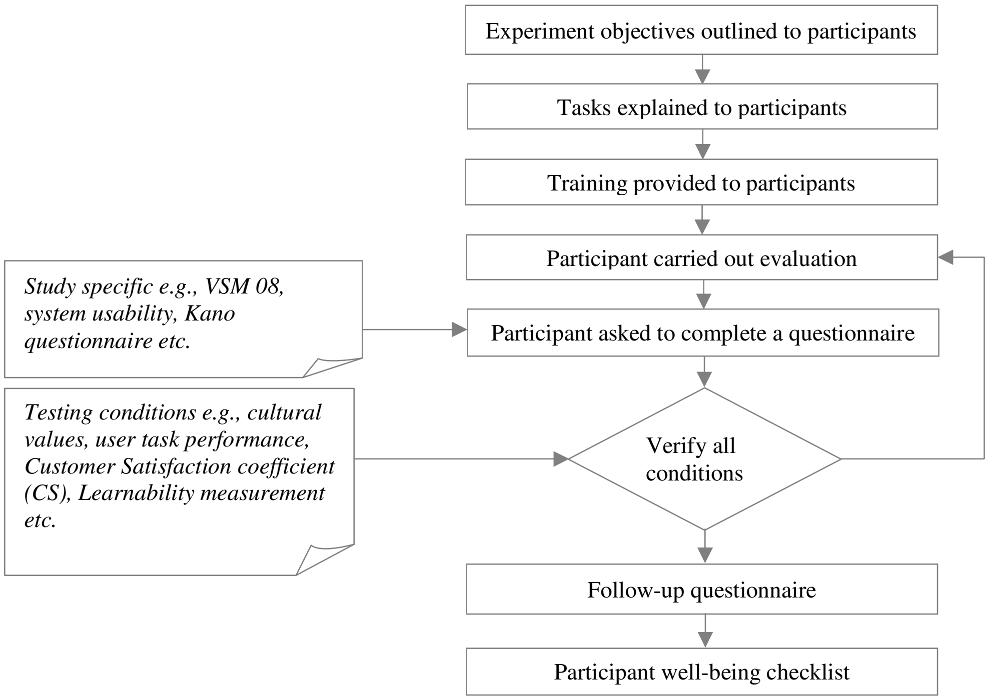


Figure 9: Procedure for evaluation studies

3.4.5 Questionnaire Design for Studies

For this research project, several experimental studies were completed to understand automotive user cultural values, their usability performances and their preferences regarding the display interface design features. Therefore, each study managed its own intended questionnaire objectives and administrative process. The questionnaire includes items measured with five-point, strongly agree, to strongly disagree Likert scales. Although some of the original instruments use a seven-point scale, it was felt that five-point scales would be more user-friendly for the samples studied. The survey questionnaires used for both cultural groups (for all studies) were identical and written in UK English language.

3.4.6 Measurement Procedures

3.4.6.1 Measurement of Cultural Values - VSM

Cultural values were measured using Hofstede *et al's,* (2008) "The Values Survey Module" (VSM08). It is a 34-item paper-and-pencil questionnaire developed for comparing cultural values of similar respondents from two or more countries (Hofstede *et al,* 2008). Respondents indicate their answers using a five-point Likert scale. The VSM08 assesses seven dimensions of culture on the basis of four questions per dimension. These dimensions include: 'Power Distance' (PDI), 'Individualism vs. Collectivism' (IDV), 'Uncertainty Avoidance' (UAI), 'Masculinity' vs. 'Femininity' (MAS), 'Long-Term Orientation' (LTO), 'Indulgence vs. Restraint' and 'Monumentalism vs. Flexhumity'. The latter two dimensions are not included in the study because rankings for the Indian culture did not exist at the time of the experiment. Thus, the project counts 5 x 4 = 20 content questions of VSM. The term module means that the questionnaire can be used as part of a larger instrument comparing countries on other aspects (Hofstede *et al*, 2008). The score for each dimension is calculated using the formulae shown in (1), (2), (3), (4) and (5).

$$PDI = 35(m07 - m02) + 25(m23 - m26) + C(pd) \qquad (1)$$
$$IDV = 35(m04 - m01) + 35(m09 - m06) + C(ic) \qquad (2)$$
$$MAS = 35(m05 - m03) + 35(m08 - m10) + C(mf) \qquad (3)$$
$$UAI = 40(m20 - m16) + 25(m24 - m27) + C(ua) \qquad (4)$$
$$LTO = 40(m18 - m15) + 25(m28 - m25) + C(ls) \qquad (5)$$

3.4.6.2 Measurement of Usability

The subjective measurement of effectiveness (Usefulness, Ease of use), efficiency (Ease of learning), and user satisfaction was carried out using USE survey items developed by usability specialists (Lewis, 1995; Lund, 2001; John *et al*, 1988), but adapted in this project to indicate the automotive HMI usability, driver task performance and efficiencies towards using the HMI system. The survey was designed in two sections (usability and system satisfaction) with a series of five-point Likert scales anchored at each end with bipolar adjectives such as difficult, confusing, adequate, easy, and very clear; e.g., "overall reaction to the software = difficult/easy". The responses were entered into numerical values 1 -5 (1= difficult….5= easy). The reason for the addition of such adjectives was to allow all participants from different cultural backgrounds to understand clearly about the survey questions. If a participant felt that they cannot respond to a particular item in the survey questionnaire, they should mark the center point of the scale (Brooke, 1996). This type of usability survey was selected for several important reasons: 1) survey items can be used to test a product or system that focuses on software usability and has compatibility with 'Questionnaire for User Interaction Satisfaction' (QUIS) and 'System Usability Scale' (SUS) tests; 2) items and variables specified in these surveys are compatible with Hornbaek's (2006) identified component of usability which is widely used by HCI experts and supported in ISO 9241-11 guidelines. Of the five-point Likert scales that constitute the majority of the measures used in the questionnaire, these scores were calculated by averaging item scores for each scale. This option was preferred to summing scores for data interpretability reasons.

3.4.6.3 Measurement of Design Preferences

The data collection and measurement regarding user HMI feature preferences was carried out using the Kano model (Kano *et al*, 1984; Section 2.3.4). In order to comply with the model, HMI feature requirements are classified using a questionnaire based on a functional and dysfunctional approach. The first of the pair of questions asks the user how he or she would feel if a feature within a requirement is available (e.g., How would you feel if vehicle GPS Navigation display provided highly structured information access for the system? – the functional form of the question); while the second part asks how he or she would feel if that feature is not available (e.g., How would you feel if vehicle GPS Navigation display did not provide highly structured information access for the system? – the dysfunctional form of the question). For each pair of questions, participants can respond in one of five different ways: i) I like it; ii) it must be that way; iii) I am neutral; iv) I can live with it; v) I dislike it (Kano *et al*, 1984). The need classification is then obtained by comparing the responses to the functional and dysfunctional questions to an evaluation table, which identifies the classification of the requirement (Matzler & Hinterhuber, 1998; Rejeb *et al*, 2008).

The analysis and interpretation of the Kano results was carried out in the following steps.

Step 1: According to Matzler & Hinterhuber (1998) and Kurt *et al*, (1996), the simplest method is evaluation and interpretation according to the frequency of answers. Hence, evaluation was carried out according to the frequencies (as percentages) of the types of response categories for each of the user interface attributes in the Kano questionnaire.

Step 2: Certain requirements may be classified in more than one category. Therefore, the rule "M > O > A > I" (Kurt *et al*, 1996) is adapted for the evaluation of responses, allowing the highest-priority category for that requirement to be identified. The strategy is that those features within UI attributes, which have the greatest influence on the perceived product quality, i.e., which cause dissatisfaction if not met have to be taken into consideration (Matzler & Hinterhuber 1998), as a priority.

Step 3: Customer satisfaction (CS) coefficients are calculated from the Kano category frequencies using the formulae, shown in (1) and (2), where A, O, M, and I signify the number of responses in the 'Attractive', 'One-dimensional', 'Must-be', and 'Indifferent' categories, as per the Kano model definition. CS indicates the extent to which satisfaction increases if a product requirement is met or the extent to which satisfaction decreases if a product requirement is not met (Berger *et al*, 1993). CS is widely used in areas such as digital products (Zhu*et al*, 2010), customer services (Sihombing*et al*, 2012), patient care (Hejaili*et al*, 2009), and automotive quality (Rashid *et al*, 2010).

$$\mathrm{CS-E\ (Enhanced)} = \frac{A+O}{A+O+M+I}\ X\ 1 \qquad (6)$$

$$\mathrm{CS-R\ (Reduced)} = \frac{O+M}{A+O+M+I}\ X\ (-1) \qquad (7)$$

3.4.7 Reliability and Validity

The internal consistency of the survey data was evaluated using Cronbach's Alpha (e.g., cultural values, usability, Customer satisfaction coefficients etc.). Cronbach's Alpha ranges from 0 to 1, with values above *0.70* deemed acceptable for advanced multi-national research (Nunally, 1978). Data reliability checks were carried out using the statistical software package, MS EXCEL, Minitab including Multivariate Analysis in order to calculate internal consistency of the survey data.

The *t*-test commonly used in cross-cultural studies to assess if variable means differ between countries and also where sample size is small and normal distribution is assumed (e.g., Sjolander, 1992; Donthu & Yoo, 1998; Malhotra & McCort, 2001; LeBlanc & Herndon, 2001; Park & Jun, 2003). Therefore, data from the VSM08, usability survey responses, user HMI task performance results and CAUI learnability were analysed using two-sided student *t*-test (8) to identify whether the average results significantly differ between cultural groups.

The hypotheses relating to the relationship between Hofstede cultural dimensions and usability variables were examined using Pearson's correlation coefficients (9). The statistical theory provides guidance on categorising the type of correlation by considering as one variable increases, what happens to the other variable as follows:

- Positive correlation occurs – if the other variable has a tendency to also increase;
- Negative correlation occurs – if the other variable has a tendency to decrease;

No correlation occurs – if the other variable does not tend to either increase or decrease.

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{(s_1^2 \div n_1 + s_2^2 \div n_2}} \quad (8)$$

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}} \quad (9)$$

Validity issues are overcome by conducting studies using the same cultural groups twice (study I and II in Section 3.2.1). Both studies employ a technical administrator from India and UK. They administer the user evaluation studies without interference from research engineer and their recommendations were taken into account to construct the survey experimental procedures and training for the participants. This ensures that the validity of the project is maintained throughout.

3.4.8 Summary

This section described the techniques by which data are generated and collected. First, the criteria considered in the selection of a cultural sample were discussed. Then the choice of the data collection technique was discussed. This was followed by the discussion about data measurement and analysis. The procedure for conducting the user evaluation was outlined in Figure 9 and data measurement and analysis procedures in Section 3.4.6. Finally, the reliability and validity of the evaluation methodology were discussed in Section 3.4.7.

The use of the nation as a proxy for culture was adopted in this research and two countries, providing opposite profiles on all the cultural dimensions were selected: India and the UK. The questionnaire design process for the project involves three variables: 1) automotive users' cultural values; 2) Their HMI design and feature preferences; and, 3) their usability of the system which includes learnability as well as satisfaction for the perceived conventional HMI as well as the culturally adapted solution.

3.5 Ethical Considerations

The research project adheres to all research code of practice specified by the Biomedical and Science Research Ethics Committee (BSREC). To this end, an application was made to the Research Ethics Committee of the University of Warwick detailing the ethical issues relating to the research. An approval was granted prior to conducting studies. A copy of the full approval letter REGO-2014-775 is included in Appendix I. Each study, defined in Chapters 4, 5 and 6, required participants' informed consent before the research commenced.

3.6 Chapter Summary

The chapter, through methodology review, built a conceptual research model upon which the research used. The research question of the study centered on understanding the influence of culture in automotive HMI as well as understanding user attitudes and their preferences towards feature design and acceptance towards a culturally adapted solution. The research methodology was, thus, designed as a development and experimental study focusing on the examination of structured hypotheses relating the variable of cultures with that of automotive user HMI usability performance. Hofstede's (1984; 1991; 2001) cultural dimensions were adopted to operationalise the culture. Two countries, the UK, and India were selected using the Hofstede cultural model for cultural sampling with students as the sampling subject for survey data collection (study I & II).

Now that the full research design has been developed and discussed, it is necessary to establish whether the output produced by the research model is valid and to test the hypotheses defined in Chapter 2, Section 2.7. The findings are discussed in Chapters 4, 5 and 6.

4 CULTURAL CONTEXT OF AUTOMOTIVE HMI

4.1 Chapter Overview

This chapter deals with the research findings related to the first study outlined in research design (Figure 7) and present the findings in a form designed to enable the research hypotheses and related analyses. This is a comparative study aimed at identifying cultural differences in automotive users' values, their HMI usability performances and investigates the correlation between cultural dimensions and usability factors.

4.2 Scope of the Study

The main objective of this study is to identify differences in cultural values and orientation across automotive users from India and UK (Section 3.4.1). The study also analyses cultural influence on driver usability performance towards HMI and how cultural theories can be used to describe the findings. In doing so, this study aims at dealing with, first, two objectives (objective 1 and 2) defined in Section 1.4. To meet these objectives, hypothesis H_1, H_2 and H_3 defined in Section 2.7 are examined. Hypothesis H_1 and H_3 are refined as per the specification of the study.

H_1. There are significant differences in cultural values and orientation between the two cultural groups (the UK and Indian) who use automotive Human Machine Interfaces, as such:

- $H_{1.1}$: The Indian cultural group will display higher 'Power Distance' (PDI) compared to the UK cultural group.
- $H_{1.2}$: The UK cultural group will display higher 'Individualism' (IDV) compared to the Indian cultural group.
- $H_{1.3}$: The Indian cultural group will display higher 'Masculinity' (MAS) compared to the UK cultural group.
- $H_{1.4}$: The Indian cultural group will display lower 'Uncertainty Avoidance' (IDV) compared to the UK cultural group.
- $H_{1.5}$: The Indian cultural group will display higher 'Long-Term Orientation' (LTO) compared to the UK cultural group.

H2. There is a correlation between an automotive user's cultural values and HMI usability performances amongst cultural groups (the UK and Indian).

H3. There are significant differences in HMI usability and task performances amongst UK and Indian cultural groups during the use of a vehicle HMI system, as such:

- *H3.1*: A significant difference exists in the 'Usefulness' attribute between the UK and Indian cultural group.
- *H3.2*: A significant difference exists in the 'Ease of use' attribute between the UK and Indian cultural group UK.
- *H3.3*: A significant difference exists in the 'Ease of learning' attribute between the UK and Indian cultural group.
- *H3.4*: A significant difference exists in the 'Satisfaction' attribute between the UK and Indian cultural group.
- *H3.5*: There are significant differences in users' HMI task performances between the UK and Indian cultural group.

4.3 *Participants Profile*

The sample selection for this study follows the specification defined in Section 3.4.3: twenty students with UK and Indian cultural background were selected to participate in the study. Table 9 illustrates the characteristics of the sample used. The demographic requirement for participants includes less than 12 months' residency for foreign participants who live in opposite cultures. Each experimental session lasted approximately 90 minutes.

Table 9: Demographic of the Study I

Demographic Data		*Cultural background*	
		India (%)	*UK (%)*
Average age (rounded)		32	35
Gender ratio	Female	20	30
	Male	80	70
Residency at current place	Between 0-6 months	70	0
	Between 7-12 months	30	0
	>12 months	0	0
	>24 months	0	0
	>36 months	0	100
Average education level		Bachelor degree	Bachelor degree
Average reported level of touchscreen experience*		41	39
Average reported driving experience **		33	41

* On a scale of 1-5, 5 is high, 1 is low (calculated % level); ** On a scale of 1-5, 5>=5 years, 1=1years (calculated % level)

4.4 Research Instruments

Throughout the experiment, participants were seated in the driver's seat of a stationary midsize Sports Utility Vehicle (SUV) in production since 2007 and sold throughout North America and European regions as well as India and China. The SUV was equipped with a touchscreen multimedia system and tactile center console and steering wheel control switches. The functionalities within touchscreen and control switches allowed users to operate contexts such as GPS 'Navigation', 'Bluetooth' telephony and the Multimedia of the vehicle's HMI system.

4.5 Data Collection Procedures

An independent experiment administrator from WMG, The University of Warwick in the UK was recruited and trained to conduct the study (administrator's participation was voluntary). The experiment administrator was trained to a required standard by research engineer to perform automotive use cases in a vehicle HMI setting. He/she was consulted before the evaluation. Based on the received and agreed information, the experimental process and logistics specific to the study was designed.

The experimental procedure of this study follows steps defined in Section 3.4.4: prior to the experiment, participants received training and an explanation regarding the control switch of the vehicle and objective of the study. Once the briefing process was complete, participants began the experiment and survey by signing a consent form and filling out pre-experiment questionnaires in order to collect their demographic information, driving experiences and cultural values (VSM08 questions). Participants were then given a series of UI tasks to complete using the display touchscreen and control switching of the vehicle. These tasks included 'GPS Navigation destination entry', 'selecting point-of-interest', 'listening to the radio', 'playing an AM/FM station using radio program type', 'adjusting sound and display settings', 'connecting to a Bluetooth phone', 'phone book search', 'accepting a hands free telephone call', 'playing a song using Bluetooth phone audio', etc. The following is an example, "Please select a music track of your choice from the music playlist and then select the shuffle feature".

The participants were observed while using the system and as they carried out these tasks. Tasks were timed using a stopwatch; however, the timing was variable in this study. If the participant did not complete the task, the timer was stopped and the experiment administrator stepped in to finish the task. This was necessary from a practical and logistical standpoint of the system. Before timing began, participants were encouraged to ask any questions about the tasks, once the stopwatch had started; the experiment administrator stepped in to clarify a task only. Clarification was required if participants seemed confused about a task to the point where they were obviously off task and unaware of it, or thought they had completed a task but in actuality had not. Participants were then asked to rate the usability of the system using 'usability and system satisfaction' survey questionnaires (Section 3.4.6.2). These are included in Appendix II.

The usability trials were adopted to gain control of the experiment. It was difficult to exactly replicate conditions for the HMI studies involving real driving tasks with variables such as weather conditions and traffic outside that are similar for both cultural groups in a different time and days. Furthermore, the primary objective was to understand the cultural impact in automotive HMI rather than assessing driving effectiveness or distraction measurement, as such, usability surveys were justified.

4.6 Measurement Process

Cultural values were examined using Hofstede's 'VSM08' described in Section 3.4.6.1. User performance towards the use of vehicle HMI was measured in two forms: firstly, by measuring the system effectiveness: in this study time was not constant, therefore, each participant had no time limit to complete all tasks. Therefore, participants either completed all tasks or announced they were unable to complete the task or did not wish to continue with a task. An incomplete task was also defined where the experiment administrator had to intervene and complete the task, i.e., the mismatch between pre-defined automotive use case scenarios and actual accomplished tasks. The result was then recorded and summated for all tasks attempted by the participants. Secondly, by measuring the system efficiency: in this measurement, two factors were counted: 1) time taken to complete a task; 2) the number of errors participants made during a task execution. Errors were defined as an attempt to use the touchscreen or tactile switch commands, including the use of display information that would not result in completing the assigned task (adapted from Section 2.6.3). The resulting scores on time taken and error made were recorded and statistically analysed; however, they were not combined to calculate efficiency. This option was adopted as per recommendation by Wallace & Yu (2009). Correlations were measured using 'Pearson' correlation theory (*r*) in two cases: common correlation between cultural dimensions and usability factors; and, statistical significance between identified common correlations. The degree of correlation is indicated by the closeness of the correlation measure to *1* or *-1*. A result of *0* indicates an absence of correlation while the following rules were applied to indicate a valid correlation:

If $r = +/- 0.5$ then it has a strong correlation.

If $r = +/- 0.3$ then it has a moderate correlation.

If $p > 0.05$ then it has no statistical significance in correlation.

4.7 Findings from the Study

4.7.1 Comparison of Cultural Values

Results from the cultural value survey show significant differences in two cultural dimensions: 'Masculinity' index (MAS) and 'Long-Term Orientation' index (LTO). The statistical results are shown in Table 10. Figure 10 shows the graphical distribution of results. Raw data from the value survey is included in Appendix III. According to the results, Indian sample scored significantly higher in MAS compared to the UK sample. However, the Indian sample scored significantly lower in LTO as opposed to the UK sample. There were differences in 'Power Distance' (PDI) and 'Uncertainty Avoidance' (UAI) but no statistical significance was found to support the evidence. On the 'Individualism' Index (IDV) both cultural groups scored almost similarly. This may be due to the samples' age group, academic background, and living standard. The results provide sufficient evidence to accept hypothesis $H_{1.3}$ (the Indian sample displays higher 'Masculinity' compared to the UK sample) and, as such, H_1 hypothesis is partially accepted. The results demonstrated an opposite result for hypothesis $H_{1.5}$: UK samples appeared to be more 'Long-Term Oriented' compared to Indian sample.

Table 10: Comparison of cultural values amongst Indian and UK participants

Cultural Dimension	*Cultural values*		*t(df)*	*p*
	UK	*India*		
Power Distance Index (PDI)	4.4443	6.6665	-0.093(16)	0.82927
Individualism Index (IDV)	38.8885	38.8892	+0(16)	0.99017
Masculinity Index (MAS)	-31.1112	62.2223	-3.263(16)	0.00511*
Uncertainty Avoidance Index (UAI)	-72.2222	-54.4445	-0.559(16)	0.54977
Long Term Orientation Index (LTO)	23.3335	-10.0002	+1.125(16)	0.02212*

* $p < 0.05$;

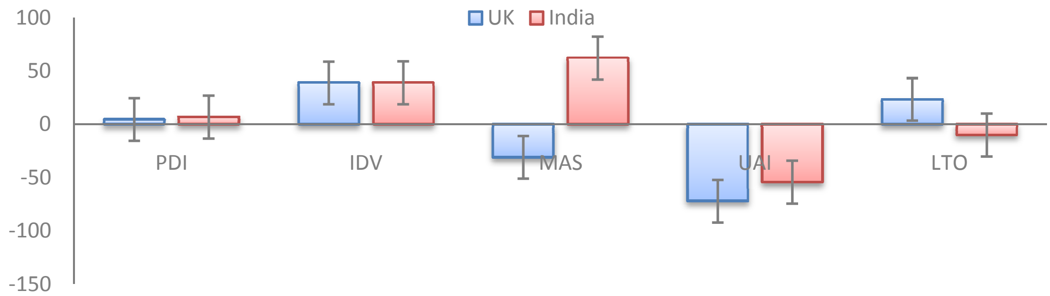


Figure 10: Graphical distribution of cultural value comparison data

4.7.2 Comparison of Usability Factors

Table 11 summarises the distribution between two groups and shows the level of consistency of the usability survey. A breakdown of each usability factor is included in Appendix IV. Data reliability shows Cronbach's Alpha over *0.70* in 'Ease of use', 'Ease of learning', and 'Satisfaction', indicating good reliability (Nunally, 1978). Average scores from UK sample in all usability factors were higher than the Indian sample. These results demonstrate that UK participants favour the overall usability and quality of the system compared to Indian participants. However, two factors where score differences were larger are 'Ease of learning' and 'Satisfaction'. Comparing the mean values of these factors using t-test for equal variances confirms that significant differences exist between the UK and Indian users for both 'Ease of learning' ($t(4)=3.889$, $p=0.017$, $P<0.05$) and 'Satisfaction' ($t(6)=3.343$, $p=0.015$, $p<0.05$). Therefore, hypothesis $H_{3.3}$ (A significant difference exists in the 'Ease of learning' attribute between the UK and Indian cultural group) and $H_{3.4}$ (A significant difference exists in 'Satisfaction' between the UK and Indian cultural group) is accepted as valid hypotheses. Appendix V illustrates the distribution of scores between the two groups in 'Usefulness' and 'Ease of use' factors.

Table 11: Comparison of usability factors amongst Indian and UK participants

Usability factors	Cultural sample Mean (SD)		t(df)	p	*Cronbach's Alpha (∞)*	
	UK	*India*			*UK*	*India*
Usefulness	27.6 (5.5)	26.8 (2.8)	0.288(8)	0.780	0.64	0.57
Ease of Use	31.0 (5.3)	27.6 (3.1)	1.236(8)	0.251	0.77	0.76
Ease of Learning	29.7 (3.1)	22.3 (1.2)	3.889(4)	0.017*	0.76	0.79
Satisfaction	35.0 (2.7)	24.7 (5.5)	3.343(6)	0.015*	0.80	0.85

* $p<0.05$;

In order to understand cultural differences in the area of ‘Ease of learning’ and ‘Satisfaction’, response data was decoded further. The analysis identifies a few specific differences related to user comprehension about the visual complexity of the information on the screen and feelings about the system not been designed for everyone. Figures 11 and 12 show the comparison of mean measures of ‘Ease of learning’ and ‘Satisfaction’ factors (summary of all questions in three categories) between the two cultural groups. The results have some indication that participants’ ‘learnability’ is a possible factor in determining the perceived usability of a conventional automotive HMI system which influences user ‘Satisfaction’.

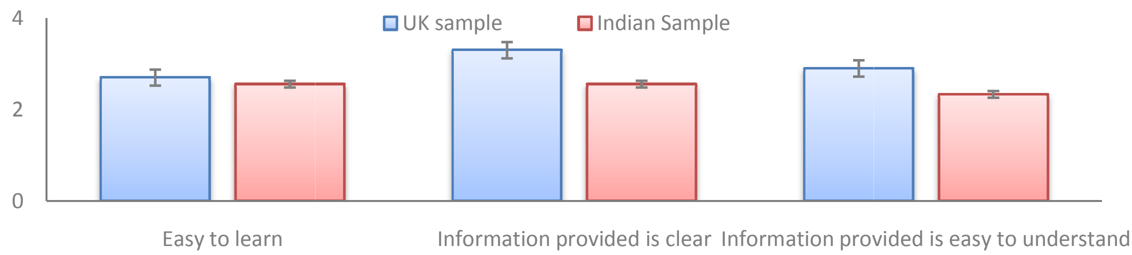


Figure 11: Comparison of mean measures of 'Ease of Learning'

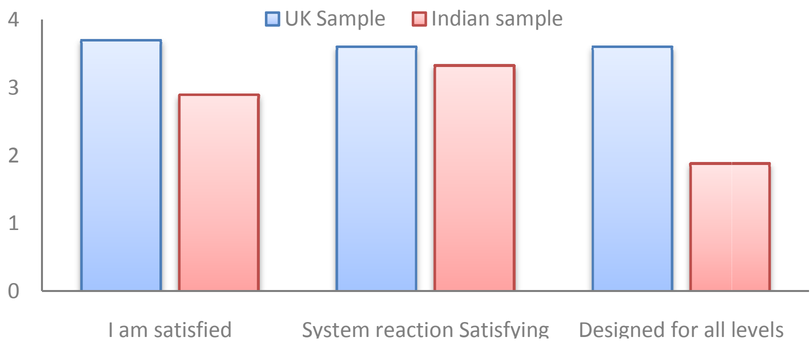


Figure 12: Comparison of mean measures of 'Satisfaction'

4.7.3 Comparison of Driver Performance

Figure 13 shows the mean task completion time (seconds) against each task category between two cultural groups. Table 12 summarises the distribution of mean completion time between the groups for each category task. On a category by category basis, the results show that the Indian sample took longer time to complete all category tasks compared to UK sample. Further analysis confirms that there are significant differences in the mean completion time of GPS ‘Navigation’ related tasks between the two groups. Figure 14 shows the comparison of timing in GPS ‘Navigation’ category tasks. This task category required information decoding and information analysis before accepting or rejecting system responses and completing tasks. Appendix VI illustrates the comparison of mean Bluetooth phone tasks completion time between two cultural groups.

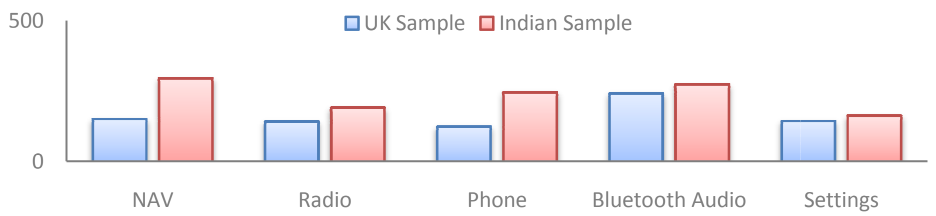


Figure 13: Comparison of mean task completion time for all tasks categories in seconds

Table 12: Group scores differences for all category tasks
(Mean completion time in seconds)

Performance factors	*Cultural sample*		*t(df)*	*p*
	UK	*India*		
GPS Navigation	151.25	295.63	-2.343(14)	0.034*
Phone	142.75	190.75	-0.982(6)	0.364
Radio	120.67	245.33	-0.805(4)	0.465
Bluetooth audio	242.00	273.50	-0.131(2)	0.908
Settings	144.50	162.00	-0.414(2)	0.718

* *p <0.05;*

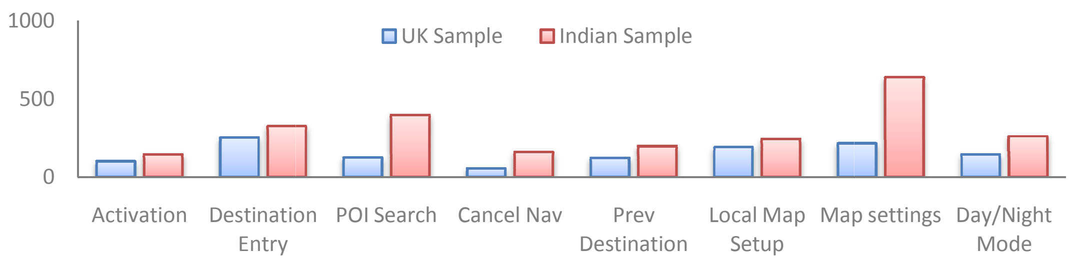


Figure 14: Comparison of GPS Navigation tasks completion time in seconds

Table 13 summarises the distribution of mean error counts against each task category amongst the two cultural groups. Comparing the mean error rate using t-test for equal variances demonstrates that there are significant differences in 'Bluetooth audio' (*t(18)=-4.657, P=0.0001, P<0.005*), 'Phone' (*t(18)=-3.924, p=0.0009. P<0.005*) and GPS 'Navigation' (*t(18)=-4.803, p=0.0001, P<0.005*) categories of tasks between the two cultural groups. Indian participants made a higher number of errors during the completion of these three task categories. The error counts also took into account the number of times administrator intervened to complete the tasks and clarify the tasks to participants. One of the root causes of the Indian participant making errors was the number of unknown icons to them (or they were not aware of them). Both groups made the least number of errors during 'Radio' related task. In summary, assessing both task timing and error count results, it can be concluded that hypothesis *H3.5* (There are significant differences in users' HMI task performances between UK and Indian cultural group) is valid for this study and, as such, *H3* hypothesis is accepted.

Table 13: Error made by cultural groups during each category tasks completion

Task Categories	*Cultural sample*		*t(df)*	*p*
	UK	*India*		
Bluetooth Audio	3.00	7.80	-4.657(18)	0.0001*
Phone	3.10	10.80	-3.924(18)	0.0009*
Radio	0.80	6.80	-1.889(18)	0.7499
GPS Navigation	6.80	10.70	-4.803(18)	0.0001*

* $P < 0.005$;

4.7.4 Correlation between Cultural Values and HMI Usability

Further analyses were carried out to observe whether the groups' cultural dimensions had any correlation with usability performances of use of the system. Correlations were verified in two cases: common correlation between cultural values and usability factors and statistical significance between identified common correlations. Tables14 and 15 illustrate the correlations (r) between usability factors and cultural dimensions measured in this study for both groups. The results demonstrate that 'Ease of learning' correlates with all cultural dimensions of Indian samples (positively (strong) with PDI and LTO while negatively (moderate) with UAI and positively (moderate) with IDV and MAS). This is similar to UK samples where 'Ease of learning' has a strong positive correlation with MAS and LTO while a moderate but positive correlation with UAI. The results also show that this common 'Usability' attribute has a more positive relationship with Indian drivers' cultural dimensions compared to the UK. For both cultural groups, LTO positively correlates with 'Satisfaction'. Other common relationships include a positive correlation between 'Usefulness' and UAI. Overall the results provide sufficient evidence to accept hypothesis *H2*, that there is a correlation between automotive users' cultural values and how they use HMI (usability performance) amongst cultural groups.

Table 14: Correlation between Usability Factors and Cultural values - UK Sample

Usability	*Cultural values*				
	Power distance (PDI)	*Individualism (IDV)*	*Masculinity (MAS)*	*Uncertainty Avoidance (UAI)*	*Long Term Orientation (LTO)*
Usefulness	-0.1808	0.0966	-0.2172	0.4041*	-0.2721
Ease of Use	-0.0283	0.2486	-0.1109	0.3076*	-0.3473
Ease of Learning	-0.2309	-0.0149	-0.3627	0.6150*	-0.2376
Satisfaction	0.0463	-0.1492	-0.4943	0.5893*	0.4449

$r^2 = 0.72$; * = $p < 0.05$;

Table 15: Correlation between Usability Factors and Cultural values - Indian Sample

Usability	*Cultural values*				
	Power distance (PDI)	*Individualism (IDV)*	*Masculinity (MAS)*	*Uncertainty Avoidance (UAI)*	*Long Term Orientation (LTO)*
Usefulness	0.1867	-0.2926	-0.3723	0.3074*	0.1845
Ease of Use	0.1399	0.2181	0.0460	0.1167*	0.3065
Ease of Learning	0.6432	0.3288	0.3241	-0.4349*	0.5730
Satisfaction	0.2336	0.3750	0.2401	0.1548*	0.3539

$r^2 = 0.67$; * = $p < 0.05$;

4.8 Summary of the Findings and Discussions

The findings from the study I (Figure 7) identified relationships between automotive users' cultural values and automotive HMI usability factors amongst cultural groups. It also identified some evidence of cultural differences in user HMI task performance during use of a conventional system and their values and orientations. Hypothesis H_1 (There are significant cultural differences in values and orientation between two cultural groups who use automotive Human Machine Interfaces) is partially accepted due to the validity of hypothesis $H_{1.3}$. Although significant differences were found on the MAS in line with Hofstede's original data (according to Hofstede (2001; 2015), India is more masculine than the UK), however, no statistical significance in cultural value differences was found in PDI, IDV, and UAI between two groups (note: this study only considered cultural value comparisons that has statistical significant rather than numeric value differences[1]). These results ran contrary to the expected direction. While Hofstede's original data (2001; 2015) show that Indian society is slightly higher on LTO compare to the UK, this study, however, found that Indian participants are 'Short-Term Oriented'. These contradictory findings are not considered to be detrimental to the study. Differences in cultural value comparisons are an outcome of the sampling specification and VSM questionnaire scales; however, the sampling equivalence (part of the specification) where both cultural groups' participants are on similar demographic dimensions such as education, driving experience and touch screen knowhow has assisted in the comprehension of the VSM08 questionnaires, helping to ensure consistent and valid responses. Furthermore, to alleviate variations in cultural dimension rankings in relation to Hofstede's original data, it is recommended that study II: Cultural Adaptation of Automotive HMI (Figure 7) runs a second comparison test on cultural values between UK and Indian cultural groups to check whether they exhibit different results than those shown in this study.

In terms of HMI usability performances, hypothesis H_3 (There are significant differences in automotive HMI usability and task performances between two cultural groups during the use of a vehicle HMI system) is fully accepted due to the validity of hypothesis $H_{3.1}$, $H_{3.4}$, and $H_{3.5}$. The study also found a correlation between user cultural dimensions and usability factors and accepted hypothesis H_2. Indian participants had opinions about quick results with limited HMI tasks. However, the results also demonstrate that they can cope with visual interface complexities and persevere until they gain full understanding of the system. When evaluating the experiment vehicle's HMI system, users from these cultural groups' showed some discrimination between all usability attributes. Some are found to be significant between the two cultural groups: 'Ease of learning' and 'Satisfaction'. The results indicate that the layout and complexity of the HMI screen influenced the Indian participant's time to learn about the system quickly and how to use the system effectively. This, in turn, affected their ability to visually perceive and interpret information and thus required a longer operating time for all tasks and efficient use of the system. The analysis also identified a few specific differences related to user comprehension about the visual complexity of the information on the screen. The behavioural impression during task execution also provided some clues about cultural influence on participants' thinking and problem-solving processes. In such scenarios participants', cultural background was found to be an important clue. For an example, during the GPS 'Navigation' task execution phase, some Indian participants were writing each command on paper and reflecting the tasks when completed. They were enquiring about each icon before using commands. These affected their times to complete HMI tasks. Therefore, efficiency may have been affected by the way they solve problems and previous knowledge about the systems. This agrees with Ito & Nakakaoji's (1996) theory that culture influences how user speaks with a visual information system. Considering the results, it is apparent that a major difference lies with each group's 'learnability' and 'time orientation' to complete automotive HMI tasks. In this regard, GPS 'Navigation 'related tasks were found to be more problematic for Indian participants.

Results show most of the common tasks, e.g., settings, radio/media control, where information decoding is less have little influence from user cultural orientation. These results may also be influenced by participants' knowledge of the consumer electronics touchscreen system (e.g., Smartphone). This was evident during the usability survey response period where each participant compared some familiar touch control functions with their own mobile devices. In summary, there are significant differences exist between the two cultural groups in their task performance in this study, however, as the results from the *t*-test showed, overall system efficiency and effectiveness has less effect when low workload related tasks are combined. Therefore, it remains a point for further study to analyse cultural differences in each automotive HMI application separately.

4.9 Chapter Summary

This chapter has set a useful scenario for the cultural context of automotive HMI which is essential for the next step of the project. To understand the cultural context of use, the cultural models incorporated and cultural relationships with the use of the automotive HMI system are investigated. Factors of usability are adopted to define the use characteristics of the target culture audience. In order to understand how to develop a UI system that is appropriately pitched to the target users, it is essential to examine the different visual representation in target cultural settings (Smith *et al*, 2004). This can be achieved by conducting an audit of available UI systems. Thus, the next stage involves the evaluation of HMI systems with observed driver preferred design characteristics.

[1] a cultural index difference is statistically significant if $p < 0.05$.

5 CULTURAL ADAPTATION OF AUTOMOTIVE HMI

5.1 Chapter Overview

This chapter deals with the research findings related to the second study outlined in research design (Figure 7) and discusses the results. This study uses the Marcus and Gould's web-interface guidelines as functional requirements described in Section 2.5.5.1 and tests their operational use in automotive use cases. Furthermore, the study I (Chapter 4) could not verify all the expected results as per Hofstede's theories and, as a result, the tests were repeated in this study with higher sample size. The implications of the outcomes are also described in this chapter.

5.2 Scope of the Study

Hypotheses H_1: $H_{1.1}$, $H_{1.2}$, $H_{1.3}$, $H_{1.4}$, $H_{1.5}$ were-examined in this study and re-evaluated. The other scopes were to:(i) explore the differences in attitudes and preferences towards automotive HMI design and feature requirements amongst cultural groups (India and the UK); and, (ii) assess what can be learned from culturally generated theories and best practices from HCI that will help in the design of automotive HMI (Objective 3, 4, Section 1.4). As a result, following hypotheses were examined.

H_4. There are significant differences in preferences for user interface attributes and features between UK and Indian automotive users.

H_5. A culturally generated UI approach, mapped into Hofstede cultural dimensions can be applied as a user requirement capture framework for automotive HMI design.

5.3 Definition of HMI User Requirements

Table 16 lists the UI requirements for the HMI solution used in the study. The requirement list was adapted from Ito & Nakakaoji's four steps of the cognitive model (1996), with additional requirements added from Marcus & Gould's cross-cultural web-interface recommendations (2000; 2015). These are mapped to the Hofstede cultural dimensions, based on Marcus & Gould's approach. The Requirements were applied to six categories of HMI display functions: Radio control, Media player, GPS Navigation, Bluetooth Phone, Menu control, and Settings. The model proposed by Kano was utilised to identify user needs and design requirement assessment in line with recommended principles defined by Berger *et al,* (1993).

Table 16: Adapted requirement definitions for the study II

Hofstede Cultural dimensions		*User interface requirements*		
Index	*Classification*	*UI Attributes*	*Features*	*Codification*
PDI	High	Information style	Provide highly structured information	$f_{1\text{-}1}$
		Access to information	Focus on authority and security of the system	$f_{2\text{-}1}$
UAI	High	Menu structure	Ensure minimum and single type menu options	$f_{3\text{-}1}$
	Low		System can have many menu options	$f_{3\text{-}2}$
	High	Text options	Provide descriptive text for features	$f_{4\text{-}1}$
	Low		Provide abbreviated text for features	$f_{4\text{-}2}$
			Each text should be supplemented by images	$f_{4\text{-}3}$
MAS	Masculine	Number of steps	Ensure limited steps for each function &feature	$f_{5\text{-}1}$
		User help	Provide a help button for each function &feature	$f_{6\text{-}1}$
			Provide informative feature for user exploration	$f_{6\text{-}2}$
		Gender distinction	Provide distinction between gender, age for feature	$f_{7\text{-}1}$
	Feminine	Aesthetic appeal	Ensure aesthetic appeal and provide colour options	$f_{8\text{-}1}$
IDV	Individualism	Content style	Option for personalisation and feedback	$f_{9\text{-}1}$
			Images of materialism; Emphasis on new	$f_{9\text{-}2}$
	Collectivism		Configurability to support cross-national symbol	$f_{9\text{-}3}$
LTO	Short-Term	Navigation style	Overall navigation style should be simple	$f_{10\text{-}1}$
	Long-Term		Navigation style can be complex and varied	$f_{10\text{-}2}$

5.4 Study Design

The evaluation studies were conducted across two physical locations: Pune Engineering College, India and the University of Warwick, UK. A faculty member from each institution served as the contact person. For the study in India, copies of the survey questionnaires, along with testing instruments and instructions were sent to the faculty member, who then directed the implementation of the study. The same protocol was used at the University of Warwick. The contact person was nominated as research administrator for the evaluation studies and was trained to a required standard by research engineer to perform automotive use cases in a vehicle HMI setting. Regular dialogue maintained with the research administrator (both in the UK and

India) prior to the first HMI evaluation session for the design and improvements of the sessions. A transcript of communication between research engineer and research administrator is attached in Appendix VII. This was done so that he/she can train participants during the experiments (step 3 in Figure 9, Section 3.4.4) and conduct the study. According to Yeo (1996), local knowledge should be used wherever possible in a user-centered research. In this regard, the research administrator was consulted during user evaluation questionnaire (Kano model questions) development and was encouraged to ask as many questions that will help in the making of a robust survey questionnaire in a cross-cultural setting (validity of the research techniques in Section 3.4.7). Based on the received information (both from the UK and India), questions for the evaluation sessions were developed to a standard that was equally understandable to both cultural groups and had equal levels of technical content. The questionnaire was then reviewed by the research administrators for the HMI evaluation laboratory sessions. The experimental procedures and survey questionnaires used for both cultural groups were written in UK English language.

Throughout the evaluation studies, research engineer remained outside of the physical locations, as such, research engineer had no influence on the outcome of the evaluations. This was adopted to understand how regional automotive users think and behave with an HMI system without the interference from outside. Thus, the overall process was designed to maintain the integrity of the user-centered cross-cultural evaluation studies.

5.5 Participants Profile

The participant selection follows the specification defined in Section 3.4.3: participants from each of the selected cultural groups were required to be either Indian or UK citizens aged 20 years or over, live in the Pune or Warwickshire regions and hold a valid driver's licence. 60 engineering students taking graduate and post-graduate level courses in Pune Engineering College and the University of Warwick were recruited for the study (30 in India and 30 in the UK).

Table 17 shows the demographic data of the two participating cultural groups. The categories were compared across groups using Fisher's Exact Test; this highlights differences between the UK and Indian samples in all categories except gender. While there were a number of differences apparent in the demographic characteristics of the sample groups, these are not considered to be detrimental to the finding of the research. Differences in education levels between the two samples are an outcome of the sampling approach; however, the higher level of education within the Indian sample has assisted in the comprehension of the questionnaires, helping to ensure consistent responses. Indian participants displayed a higher level of geographic mobility, reflecting trends towards increases in urban populations in the country (Abbas & Varma, 2014). The differences in driving experience may also reflect broader trends of vehicle ownership across the two countries (Kalmbach *et al*, 2011). While UK users tend to have a greater degree of prior automotive touchscreen experience, all of the participants in the study received training on touchscreen tasks and achieved the required level of competence prior to taking part in the study.

Table 17: Demographic of the study II participants

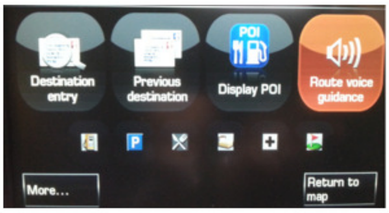
Characteristics		Cultural background		*p*
		UK (%)	*India (%)*	
Gender	Male	83.33	86.67	1.00
	Female	16.67	13.33	
Education	Bachelors	36.67	0	0.00
	Masters	63.33	100	
Living in current place	1-2 years	14.29	13.33	0.00
	2-3 years	7.14	43.33	
	3-4 years	0.00	16.67	
	>4 years	78.57	26.67	
Driving experience	1-2 years	7.14	36.67	0.00
	2-3 years	0.00	33.33	
	3-4 years	7.14	10	
	4-5 years	0.00	6.67	
	>5 years	85.72	13.33	
Experience with touchscreen system	1-2 years	7.15	36	0.00
	2-3 years	0.00	30.67	
	3-4 years	14.28	16.66	
	4-5 years	21.42	10	
	>5 years	57.15	6.67	

5.6 Data Collection Procedures

Data was collected over three weeks in July 2014 at six automotive HMI evaluation sessions run at the Pune Engineering College and the University of Warwick. Each session involved 10participants and lasted approximately 60 minutes.

Two samples of automotive touchscreen UIs, based on HMI from two production vehicles, were chosen to be assessed in the laboratory. The selected samples were adapted from existing systems, ensuring that the intended context of use was preserved during the evaluation as recommended by Hassenzahl, (2004). Two criteria were used to select the touchscreen HMI samples: firstly, the touchscreen information and layout style had to be recognised by both cultural groups. Secondly, the vehicle type and tablet used had to be available in both the UK and Indian markets. Figure 15 shows the samples of display screen layout associated with the HMI feature requirement. The interfaces were de-branded and presented on a 7-inch Android tablet in order to minimise product bias; this was integrated into a static development vehicle interior cockpit for the evaluation as shown in Figure 16. The cockpit was also equipped with tactile center console and steering wheel switches; along with the touchscreen, these allowed users to operate GPS 'Navigation', 'Bluetooth hands-free telephony' and 'Multimedia' functions of the vehicle's HMI.

Sample A: Structured information *(f1-1)*



Sample A: User exploration *(f6-2)*

Sample B: Text with image and icon *(f4-3)*

Sample B: Descriptive text type *(f4-1)*

Figure 15: Screen layout samples associated to HMI feature requirements

Step 1: Prototype is tested for functional operation in laboratory before integration into a vehicle

Step 2: Prototype is then integrated into a laboratory based vehicle interior cockpit

Figure 16: Experimental environment of study II

Participants began the experiment and survey by signing a consent form and filling out demographic and VSM08 questionnaires. Participants were given a series of UI tasks to complete using the touchscreen and cockpit switches. These included display menu settings, selecting a music track, making a telephone call, and selecting a destination using GPS

Navigation. The following is an example of the sequence of a task: The research administrator reads the task aloud before execution, for example: "Please navigate to the telephone directory in the touchscreen. Please find Christopher's contact information by using the scroll down contact list in the telephone directory and make a call to Mark on (+44(0) XXXXX-XXX027 (UK laboratory) or +91(0) XXXX-XXXX006 (Indian laboratory)". A task was counted as successfully completed if the HMI came to a logical standpoint, e.g., if an outgoing call screen was displayed. A task was counted as unsuccessful if there was no logical screen displayed or the participant announced he/she was unable to complete the task or did not wish to continue with the task.

Following the completion of all UI tasks, participants were given a Kano model-type questionnaire and asked to rate their preferences based on their HMI use experiences. Questionnaire pack also included 17 images of the HMI screens in power point slides (from either sample A or B) reflecting each of the 17 functional requirements defined in Table 16. Each of the representing images clearly labelled associated display HMI functions such as 'Phone menu display', 'Music track scrolling list display', etc. so that participants can look at the images and match each of the questions with the used functions and understand what to respond. Participants were asked to complete the questionnaire alone and not to discuss their responses or opinions with one another or the administrator and were separate from the group (they responded to the questionnaire independently).

The Kano questionnaire contained functional and dysfunctional forms of 17 questions for each of the HMI tasks categories, e.g., 'Phone', 'Media player' etc. for example: "How would you feel if the vehicle display visual interface system provided menu selection options in the phone display screen?" (Functional form) and "How would you feel if the vehicle display visual interface system did not provide menu selection options in the phone display screen?" (Dysfunctional form). Appendix VIII shows a set of 'Bluetooth phone' application Kano model questions of the study.

5.7 Findings from the Study

5.7.1 Comparison of Cultural Values

Results from the cultural value survey are shown in Table 18. Significant differences are observed in PDI, IDV and LTO indexes between the two cultural groups. The results show that the participating Indian sample tended to be more 'Long-Term Oriented' and possess high 'Power Distance' while exhibiting lower scores for 'Individualism' and 'Uncertainty Avoidance'. In comparison, the participating UK sample is more 'Individualist', 'Short-Term Oriented' and scores higher on 'Uncertainty Avoidance'. There was no statistical significance observed in the MAS and UAI index. Data reliability shows Cronbach's Alpha (α) over *0.70* in all cases, indicating good reliability (Nunally, 1978). The results clearly provide evidence to accept the hypothesis (H_1) that significant differences ~~exists~~ in cultural values and orientation between the two tested cultural groups (India and the UK) who use automotive HMI.

Table 18: Cultural values amongst participating groups

Cultural Dimension	Cultural values				Cronbach's Alpha (α)	
	UK	*India*	*t(df)*	*p*	*UK*	*India*
Power Distance Index (PDI)	50.83	102.67	-3.24(31)	0.002*	0.955	0.714
Individualism Index (IDV)	149.27	52.67	6.74(39)	0.000*	0.792	0.703
Masculinity Index (MAS)	73.78	82.83	-0.57(32)	0.569	0.895	0.704
Uncertainty Avoidance Index (UAI)	07.78	0.50	0.33(39)	0.737	0.996	0.906
Long Term Orientation Index (LTO)	30.83	91.33	-2.96(32)	0.005*	0.707	0.927

* = $p < 0.05$

5.7.2 Comparison of Feature Preferences

Comparison results of the Kano model questionnaires and customer satisfaction coefficients are shown in Table 19. The mean customer satisfaction coefficient (CS-E & CS-R) was higher for Indian participants than for those from the UK. Comparing the mean CS values across cultural groups using the t-test for unequal variances confirms that significant differences exist between the UK and Indian participants for both Extent of Satisfaction ($t(25.3)=2.07, p=0.049, p<0.05$) and Extent of Dissatisfaction ($t(27.1)=-2.42, p=0.023, p<0.05$). This confirms the hypothesis H_4 that there are significant differences in the preferences of UI attributes and features between the two cultural groups of automotive HMI users (India and the UK).

Table 19: Comparing Kano responses and customer satisfaction amongst cultural groups

	Participants' responses on Kano Questionnaire								Cronbach Alpha (α)		Customer Satisfaction Coefficients (CS)			
	Must-be (M)		Attractive (A)		One-dimension (O)		Indifferent (I)				Extent of Satisfaction (CS-E)		Extent of Dissatisfaction (CS-R)	
	UK	*India*	*UK*	*India*	*UK*	*India*	*UK*	*India*	*UK*	*India*	*UK*	*India*	*UK*	*India*
f1-1	14.29	20	21.43	23.33	42.86	26.67	21.43	23.33			+0.64	+0.54	-0.57	-0.50
f2-1	0.00	10	0.00	3.33	0.00	20.00	21.43	40.00			+0.00	+0.32	-0.00	-0.41
f3-1	21.43	13.33	21.43	13.33	21.43	16.67	35.71	43.34			+0.43	+0.35	-0.43	-0.35
f3-2	0.00	16.67	0.00	3.34	14.29	23.33	42.86	23.33			+0.25	+0.40	-0.25	-0.60
f4-1	0.00	26.67	0.00	16.67	0.00	6.66	50.00	40.00			+0.00	+0.26	-0.00	-0.37
f4-2	0.00	13.33	21.43	10	0.00	10.00	42.86	36.67			+0.33	+0.29	-0.00	-0.33
f4-3	14.29	20	28.57	16.66	28.57	26.67	21.43	26.67			+0.62	+0.48	-0.46	-0.52
f5-1	0.00	26.67	14.29	16.66	64.29	43.33	21.43	6.67			+0.79	+0.64	-0.64	-0.75
f6-1	14.29	23.33	14.29	13.34	14.29	33.33	35.71	23.33			+0.36	+0.50	-0.36	-0.61
f6-2	0.00	23.33	14.29	16.66	14.29	30.00	35.71	26.67			+0.44	+0.48	-0.22	-0.55
f7-1	7.14	26.67	7.14	16.66	0.00	23.34	42.86	16.66	0.97	0.98	+0.13	+0.48	-0.13	-0.60
f8-1	0.00	0	7.14	23.33	7.14	13.34	57.14	33.33			+0.20	+0.52	-0.10	-0.19
f9-1	7.14	20	35.71	10.00	14.29	33.33	28.57	30.00			+0.58	+0.46	-0.25	-0.57
f9-2	0.00	20	0.00	30.00	0.00	13.33	28.57	3.34			+0.00	+0.65	-0.00	-0.50
f9-3	0.00	20	7.14	23.33	7.14	26.67	21.43	20.00			+0.40	+0.56	-0.20	-0.52
f10-1	28.57	13.33	0.00	36.68	64.29	33.33	0.00	3.33			+0.69	+0.81	-1.00	-0.54
f10-2	0.00	0	0.00	23.33	0.00	0	0.00	10.00			+0.00	+0.70	-0.00	-0.00
Mean	6.3	17.3	11.3	17.5	17.2	22.4	29.8	23.9			0.34	0.50	0.27	0.47
(SD)	(9.1)	(8.2)	(11.3)	(8.7)	(21.3)	(11.2)	(15.6)	(12.7)			(0.26)	(0.15)	(0.28)	(0.18)
p	0.0008 (p < 0.05)		0.0879 (p > 0.05)		0.3884 (p > 0.05)		0.2361 (p > 0.05)				0.049 (p<0.05)		0.023 (p<0.05)	

Based on the method proposed by Berger *et al*, (1993) and referenced by Xu *et al,* (2009), a two-dimensional Kano diagram is established by plotting CS-E against CS-R for both cultural groups, as shown in Figure 17. According to the model, the diagram is divided into four quadrants representing the four Kano requirements categories and, accordingly, the UI features are classified by their CS scores.

The Kano diagram (Figure 17) shows that none of the features are identified as 'Must-be' requirements by UK participants. Indian users identified "Many menu options" (*f3-2*) and "Informative feature for user exploration" (*f6-2*) as 'Must-be' requirements; this indicates that Indian users held opinions on functional requirements for vehicle HMI. Notably, "Allow user exploration" (*f6-2*) and "Help option in system" (*f6-1*) attract similar scores for the Indian group, indicating potential dissatisfaction if not adequately delivered. Both of these requirements relate to access to user help functions within the system, highlighting the importance of support functionality to Indian users. "Personalisation option and feedback" (*f9-1*) and "Text with image option" (*f4-3*) were identified as 'Attractive' requirements for UK users, while "Complex navigation style" (*f10-2*) and "Aesthetic appeal and colour option" (*f8-1*) were 'Attractive' requirements for Indian users. The result for (*f9-1*) is interesting as UK users scored significantly higher on the IDV and might, therefore, be expected to identify it as a 'One-dimensional' requirement, placing a higher degree of importance on personalisation features. "Highly structured information" (f_{1-1}) and "Limited task options" (f_{5-1}) each attracted similar scores from the UK and Indian groups, identifying a common need for these features across cultures. All three are 'One-dimensional' attributes, signifying a proportional relationship between delivery and satisfaction, and all relate to the clarity of information presentation, which will influence the usability of the system. Although no significant difference was observed for the UAI, Indian participants scored low in this index and Choi *et al*, (2005) identify that users from low UAI cultures can cope well with ambiguity, and can be characterised as risk-takers, with a positive attitude towards new experiences (Hofstede, 2001). This is reflected in the CS-R rating of "Allow user exploration" (f_{6-2}) for Indian users, indicating that restricting the users' ability to explore the system will cause dissatisfaction. The requirement "Simple navigation style" (f_{10-1}) is 'One-dimensional' for both UK and Indian users, however, the requirement "Complex navigation style" (f_{10-2}) is also an 'Attractive' feature for the Indian user group. These two requirements are seemingly contradictory ("simple" vs. "complex"), yet there is potential for increased satisfaction if the "complex" style can be implemented without disrupting delivery of the "simple" style, for example, with a configurable display setting; this must, therefore, be carefully managed in the design of HMI. "Images of materialism and emphasis on new" (f_{9-2}) and "Complex navigation style" (f_{10-2}), also have a positive influence on satisfaction for Indian participants (CS-E scores 0.65 and 0.70 respectively), with (f_{9-2}) also influencing dissatisfaction, it is suggested that a "high-tech" appearance to touchscreen HMI is desirable for Indian users. "Images of materialism and emphasis on new" (f_{9-2}) also exhibits the largest difference between the two cultural groups; while there is zero influence on satisfaction or dissatisfaction for UK users, the requirement sits on the boundary of 'Attractive' and 'One-dimensional' for Indian users (*CS-E = 0.65, CS-R = 0.50*). This serves as a clear illustration of difference between the user needs and preferences of the two cultural groups.

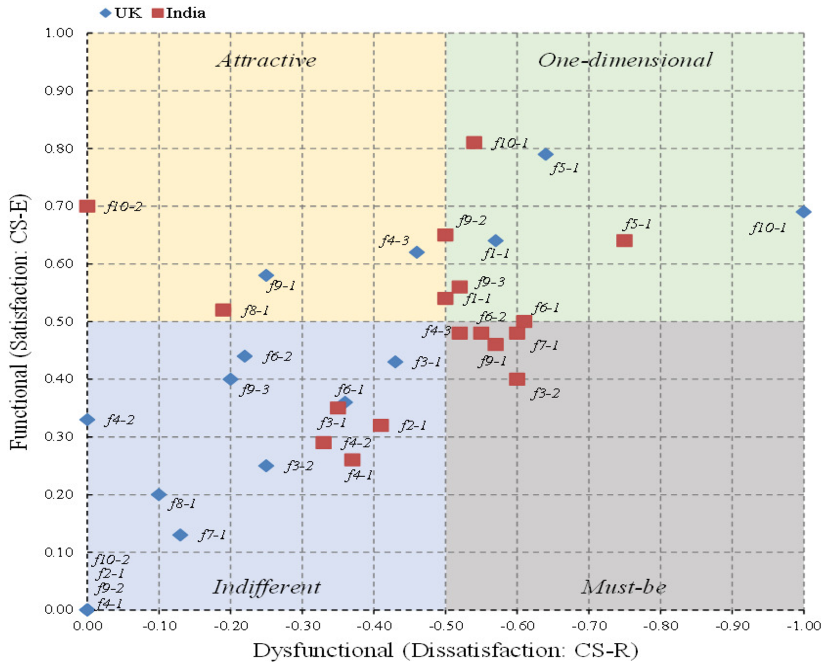


Figure 17: Customer satisfaction coefficient diagram

5.8 *Summary of the Findings and Discussions*

The study I in Chapter 4 could not verify all the expected results as per Hofstede's cultural theories and, as a result, the tests were repeated in this study with higher samples. This study also could not verify all the expected results as per Hofstede's cultural theories. For example, the MAS and UAI indices presented a pattern contrary to the expected direction. It is interesting to note that MAS index presented a significant difference between the UK and Indian samples in Chapter 4. Therefore, taking all results into account, it can be concluded that the outcome of the differences in cultural values in this research study is inconclusive.

The findings suggest that regional differences can influence the acceptance of automotive HMI display features and, as such, culturally generated UI methodologies of HCI can be applied as a basis for future automotive HMI design. Thus, hypothesis *H5* (Culturally generated user interface approach mapped into Hofstede cultural dimensions can be applied as a user requirement capture framework for automotive HMI design) is accepted for this study. Selection of features appears to be culturally biased: for example, Indian participants tended to be 'Collectivist' and possess high 'Power Distance' and were satisfied when features such as "user help", "gender distinction" and "cross-national symbol" were implemented in the HMI system. Therefore, automotive HMI designers should pay attention to these types of needs when designing for a region where these cultural values are prevalent. Analysing the results, it can be hypothesised that complexity within the display menu navigation styles provides high levels of satisfaction to Indian automotive users whose cultural dimensions correlate with 'Long-Term Orientation' in this study, but the absence of complexity does not induce dissatisfaction. With regards to the "limited tasks option" feature, the study found that both cultural groups regard this as a 'one-dimensional' requirement. The results also show that Indian participants found emphasis on a new idea or material and aesthetic appeal and colour option very attractive. In addition, options to provide content personalisation and legible text are potential delight features for UK participants if successfully implemented. The study found that both UK and Indian participants regard the limited tasks option as 'One-dimensional' requirement. Both groups also score highly on MAS index; this agrees with Marcus & Gould's (2000; 2015) guidelines, suggesting that in a 'Masculine' culture, there will be preference for simplified user interfaces (Khan *et al*, 2016).

5.8.1 Instruction Design for the Study

In this study HMI task instructions for participants were designed to focus on the system and its explicit functional behaviour as opposed to user attitude towards its operation. The instructions were developed using three basic principles of 'deductive instruction development' proposed by Thornbury (1999), a) clear presentation of the task & rules (e.g., find an item on the screen or press a button, etc.); b) highlight of the structure of HMI function (e.g., Phone or Radio related task etc.); c) definition of the task itself (e.g., make a call or cancel a function etc.). The Instructions were written in a simple plain English language which was descriptive in nature and avoided abbreviated textual information. This approach was adapted from Young *et al*, (2011) recommendation on the automotive experimental instruction design for Chinese participants. Furthermore, Ding & Jablonski (2001) stated that an Asian participant in any experiment tends to focus on technical terms & expressions instead of rhetorical issues such as audience, purpose, page layout, etc. As such, the format of technical instruction used in the study for both Indian and UK engineering students who had knowledge about driving and touch screen technology was similar to the pattern recommended by Ding & Jablonski and suitable for the experiment.

5.9 Chapter Summary

This chapter summarises the research findings from Study II (Figure 7). The study systematically explored cultural differences in automotive HMI visual design requirements between the Indian and UK cultural groups. To analyse the differences in the users' comprehensions and preferences in display information, content, navigation styles, menu structures, and complexities, the developed cross-cultural UI guidelines for web interfaces were used in the automotive context. The findings provided evidence for the hypotheses that such guidelines can be used as the foundation for future design localisation considerations. These considerations are likely to have the influence on design appeal, acceptability, and usability to drivers' from different cultural regions. The findings emphasize the importance of encoding culturally sensitive features that are likely to facilitate design and system acceptance and should be incorporated at an early stage in the design process. That is, designing products that connect cultural and emotional factors with users is likely to facilitate product acceptance (Moalosi *et al*, 2007).

The experimental process together with study outcomes at this stage provided a valuable contribution to the overall research project and proved the need for design customisation for the local automotive market. The acquired knowledge can now be used in the next stage of this research project that involves the application of knowledge into a vehicle design programme in order to check the validity of recommendations (industrial application). This stage (Chapter 6) focuses on a conceptual development, prototype integration and system effectiveness test and results analysis.

6 APPLICATION OF CULTURALLY ADAPTED HMI

6.1 Chapter Overview

This chapter describes how the research findings are applied in a real-time industrial application. The research objectives outlined in this phase inquire whether the findings generate an output that provides useful information to implement a culturally adapted automotive HMI solution in sponsoring company's vehicle platforms. This chapter also enquires whether such a solution, once implemented, has greater potential for success in terms of drivers' satisfaction and usability, compared to a non-adapted solution.

6.2 Scope of the Application Study

The primary goal at this stage is to generatea technology demonstration and an evaluation report for the target automotive manufacturer's product management so that the objectives set out in Section 1.4 can be implemented (objective 5 and 6). To achieve this, it is necessary to: i) implement the test outputs from the previous studies (Chapter 4 and 5) in the form of functional and process requirements in a vehicle design programme; ii) construct and validate a culturally adapted vehicle HMI solution prototype for end user evaluation; and, iii) review outcomes and provide recommendations for future development strategies based on evaluation studies. To meet these objectives, hypothesis *H6* and *H7* in Section 2.7 are examined. Hypothesis *H6* is refined as per the specification of the study.

H6. The research findings will facilitate the development of culturally adapted HMI solution to measure automotive users' usability and task efficiencies, as such:

- *H6.1*. Indian automotive users will exhibit lower levels of HMI task efficiencies in terms of learnability with a new, culturally adapted solution in comparison to a conventional solution; however, their efficiency will significantly improve with repeated exposure.

H7. Indian automotive users' will exhibit higher levels of satisfaction towards a culturally adapted automotive HMI solution once they are used to the system compared to the non-adapted solution.

The construct of ‘learnability’ within the context of this study, is adapted from the definition described in Section 2.6.2: the interaction with a vehicle visual display system that allows drivers to understand how easy it is to handle a specific user interaction, and to improve the performance level quickly. The construct of ‘usability’ is adapted from the definition described in Section 2.6.1: a construct comprising a driver’s perception of the automotive HMI system’s ‘Usefulness’, ‘Ease of use’, ‘Ease of learning’, and ‘Satisfaction’.

6.3 Definition of CAUI and non-CAUI HMI Solution

In this study, a ‘non-adapted’ or non-CAUI solution (Culturally Adapted User Interface) refers to vehicle Infotainment and center console display visual UI that is designed exclusively for a given automotive market and has no potential for optimisation to regional driver preferences (the majority of this will be for Western customers). An ‘adapted’ or CAUI solution, on the other hand, offers configuration opportunities based on UI feature requirements defined in Table 20 to suit regional drivers’ preferences (regional drivers’ refers to Indian participants in this study). These configurations are software tuned capabilities of the system that can adapt to user selections and expectations in accordance to an automotive manufacturer’s target market and contextual situation, which can be a means to compensate cultural differences adequately (Heimgartner, 2012).

A local adaptation of a software UI application for a target market requires not only the localisation of the text that is displayed but also the documentation language, instructions manual, menus, help functions, error messages, etc. (Olaverri-Monreal & Bengler, 2011). This implies a correct representation of culturally adapted UI solution, with symbol and icons, (Ossner, 1990), language and colour selection option (Fernandes, 1995) and reading directions (del Galdo, 1990). As such, Figure 18 illustrates examples of adapted representation of text, icons, language and colour selection within CAUI solution from a non-CAUI production system for the study (user configuration between non-CAUI and CAUI features are an option within the developed prototype solution).

Feature/Selection	Displayed in Non-CAUI solution	Changes made in CAUI solution	Example screen shot (how they implemented – colour option)
Media Player	Music	संगीत	
Bluetooth Phone	Handsfree	कॉल	
GPS navigation	Map	नक्शा	
OK/Accept	[Ok]	Register/रजिस्टर	
Colour OR language selection	This feature doesn't exists	भाषा चुनें / रंग का चयन करें	

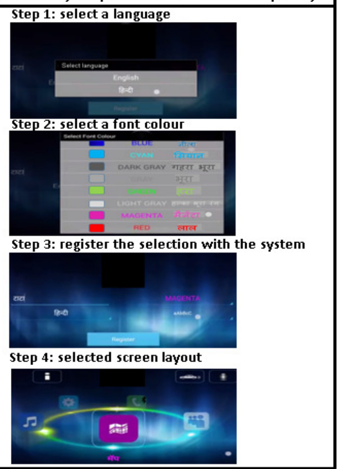


Figure 18: Examples of text and icon representation of the CAUI solution

The requirement list for the CAUI solution was adapted from Marcus & Gould's cross-cultural web interface recommendations (2000; 2015). The application of these requirements in an automotive environment was examined in Chapter 5. These requirements were applied to an aftermarket imported HMI solution to the sponsor company's vehicle that is in production since late 2013. The production solution was developed and exported by a European tier 1 supplier and is represented as non-CAUI solution for the study. The modified prototype solution is represented as CAUI solution. The modification to the production solution includes changes in visual display attributes (look and feel) of the existing HMI to support five dimensions of Hofstede's cultural model. The technical functionality and underlying application use cases of the Infotainment functions such as Bluetooth Phone, GPS Navigation, and Radio remain unchanged (i.e., UI software was separated from application logic and software). The key visual changes made to the production solution (non-CAUI) to achieve CAUI solution is illustrated in Figure 19.

Table 20: Requirement definitions of the prototype system

Cultural dimension		*UI Attributes*	*Marcus & Gould HCI recommendation*	*Derived CAUI HMI feature requirement*
PDI	High	User help	Focus on expertise, authority and experts. Importance of security and restrictions to access.	Provide high level of support to the driver by means of 'Help Option'. Provide error message in case of system malfunction.
IDV	Low	Language option	Emphasise collectivist culture and tradition and history.	Language translation for the system should be developed for user friendliness.
MAS	Mid to High	Text with image	Traditional gender/family distinctions. Graphics, sound and animation used for utilitarian purposes.	Representative image should be developed to supplement text information.
UAI	Low to Mid	Navigation and content style	Complexity with maximal content and choices. Acceptance of wandering and risk.	Complex navigation with low information density should be used within display HMI.
		Colour options	Coding of colour to maximise information	Different colour schemes and colourfulness should be provided to attract user attention.
LTO	Mid to High	Menu structure	Content focused on practice and practical value. Patience in achieving results and goals.	Several menu options (both linear and nonlinear) can be used to provide an understanding of underlying concepts)

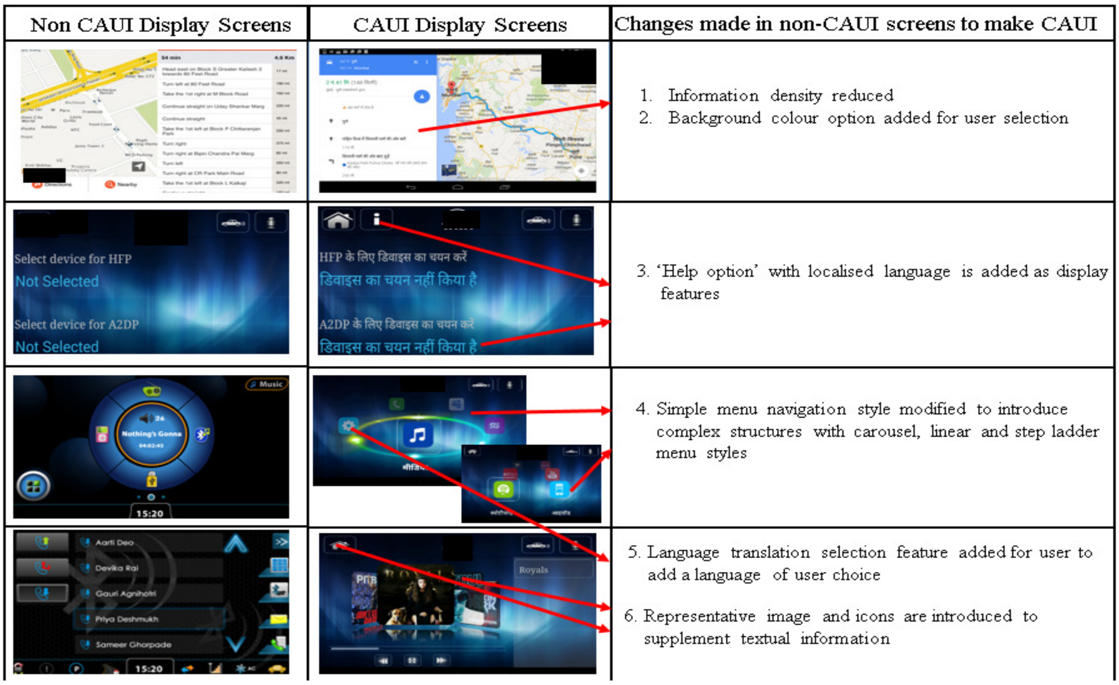


Figure 19: Requirement changes made to production solution to develop the CAUI prototype

The interfaces of the CAUI solution were de-branded due to a supplier contractual agreement and presented on a 7-inch Android touchscreen tablet. An interface between supplier black box which housed all Infotainment functions and tablet were developed using an automotive Infotainment software communication protocol. The communication allowed the tablet to send UI command to supplier black box and receive feedback about the command whenever a user uses the system. The complete solution was integrated into a production sedan vehicle's interior cockpit. The existing non-CAUI HMI display was deactivated and steering wheel control switch connections were routed to the tablet display. These connections allowed evaluation participants to operate GPS ‘Navigation’, ‘Bluetooth hands-free telephony’ and ‘Multimedia’ functions of the CAUI HMI solution.

Figure 20 shows the comparison of both CAUI and non-CAUI fitted vehicle interiors used for the evaluation study. The figure also shows design implementation strategies for CAUI fitted vehicle along with the system integration approach of tablet display in the center console area. There were a few limitations with CAUI prototype integration approach. Firstly, CAUI solution could only be operated using a touchscreen interface and steering wheel buttons as opposed to touchscreen, steering wheel, voice command, and center console rotary arm controller for non-CAUI solution. Secondly, CAUI solution was a low-fidelity rapid prototype, as such, it was integrated less aesthetically compared to the non-CAUI solution in the vehicle center console (it was integrated without any supplier assistance and with limited financial resources). Although both of these limitations were clearly visible in the CAUI fitted vehicle during the studies, a clear evaluation purpose, and technical objectives for such integration together with a training policy was defined and communicated internally to the sponsoring company’s product and marketing management and evaluation participants. Therefore, in accordance with study objectives, the emphasis was placed on the usability and learnability data of the proposed CAUI development strategies and look & feel and ergonomics measures were excluded from the evaluations. Furthermore, use cases defined in the evaluation did not consider any vehicle UI task with center console rotary arm controller (Figure 20); as such both solutions were at par with UI command and control.

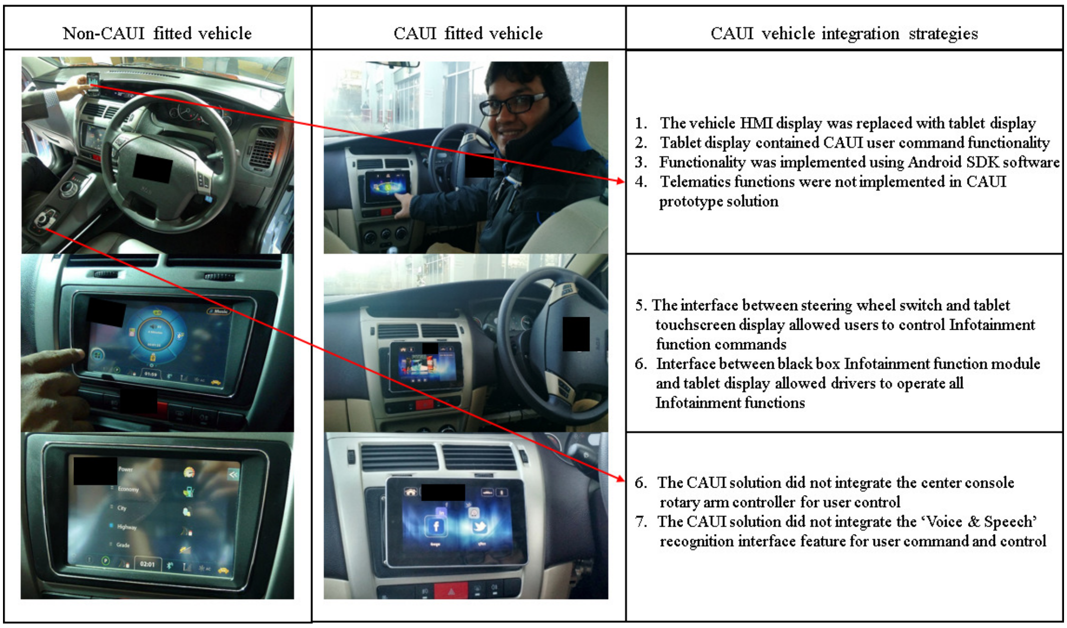


Figure 20: Comparison between non-CAUI and CAUI solution's integration approaches

6.4 Participants Profile and Evaluation Process

A series of HMI user studies were prepared to execute the CAUI prototype evaluation during 2015 in sponsoring company's 'Engineering Research Center', Pune, India. Thirty Five Indian native technical professionals (25 male and 10 female), between the ages of 25 – 45 years (*Mean= 33.8; SD=5.7*), were recruited for the evaluation studies. Participation in the study was voluntary. Of the 35 participants, all had a valid Indian driver's licence and drove 10,000 or more miles per year. In addition, all the participants had experience of using touchscreen devices in their own car. The technical competencies of the participants assisted in the comprehension of the evaluation tasks and questionnaires, helping to ensure consistent responses.

An independent evaluation study administrator from a consultancy service in India was recruited and trained to conduct the studies (administrator's participation was voluntary). The study administrator was consulted during the evaluation process and questionnaire development. Based on the received and agreed information, evaluation sessions were designed and questions for the evaluation sessions were developed to record participants' feedback. This is to ensure that the research engineer from the UK would not influence the outcome of the evaluation by imposing his own view regarding CAUI solution (validity of the research, Section 3.4.7 and CUI design recommendation by Yeo, 1996).

In order to evaluate adapted and non-adapted solution, both CAUI and non-CAUI fitted vehicles were positioned side by side so that participants can understand the differences during evaluation sessions and save times. The complete evaluation process was carried out in three phases and was separated into two evaluation studies: 'learnability' and usability evaluation. During 'learnability' evaluation, participants evaluated non-CAUI vehicle first and then proceed to CAUI vehicle. Participants were not required to drive any vehicle and asked to evaluate only predefined secondary HMI tasks with the solutions in a static vehicle.

The overall process complied with the research data collection methodologies defined in Section 3.4.4. Each phase of the experimental session lasted one hour. Prior to the experiment, participants received training to familiarise them with the basic operations of both systems. In the first phase ('learnability' evaluation), the participants were given a series of UI tasks to complete using the display touchscreen and steering wheel switches in both non-CAUI and CAUI vehicles (same tasks for both vehicles). The tasks used for this study were abstracted 'find and select' whereby the participant is required to find and press a target button from the steering wheel switch or touchscreen. These tasks included display menu settings, selecting a music track from the menu list, search and selection of an item from the menu list, selecting help options about a specific Infotainment function, selecting colour options, using the menu options, dialling phone digits, map selection etc. Appendix IX lists examples of tasks used in the evaluation studies.

The successful completion of a task by a participant was determined by the display coming to a logical standpoint, e.g., if the GPS Navigation map screen was displayed when 'Map' was selected in the previous screen regardless of audio feedback. An unsuccessful task was the result of a participant announcing that he/she was unable to complete the task or did not wish to continue with a task. When participant announced he/she completed a task this was recorded immediately by the evaluation administrator (as well as task attempts). There was no time limit to complete each task; however, the overall evaluation period was limited to 60 minutes. Therefore, participants completed as many tasks within the overall evaluation period as there was time for. In the second phase of the 'learnability' evaluation, participants were asked to return after a week and repeat the evaluation process as per phase 1 in the CAUI vehicle only. The idea behind phase 2 was to observe any differences or improvement in user performance, e.g., whether user learning and adaptation improved over repeated use. In phase three, once both evaluations are completed, participants were invited to rate both the CAUI HMI and non-CAUI HMI based on their use experiences (usability evaluation). The goal was to identify, given the choice, which system would be more usable and satisfying to the participants.

This experimental approach was adopted for several reasons. Firstly, it was difficult and expensive to develop experimental procedures for the studies involving real driving tasks in Indian traffic conditions. Recording devices needed to be integrated to record their system use behaviour as well as the safety of participants in a dynamic condition (including costs of insurances). This intrusive monitoring could have a negative influence on the participants' tasks responses or engagement with the study. Secondly, the usability evaluation allowed experiments to be reset (in the case of a technical fault of the experimental system) and run far more quickly and allowed participants engagement in multiple trials with consistent conditions. According to Skelton (1992), usability results provide largest positive impact during the initial investigation, definition, and design phases. Therefore, it was appropriate to utilise usability evaluation for this study.

The analysis and interpretation of participants' learnability were then carried out using the following steps:

Step 1: User task completions were measured by recording binomial (yes= successful task; no= unsuccessful task) results of all tasks attempted by the participants. The results of the number of successful tasks each participant completed in both trials were analysed to check whether any difference existed between them. Once done, improvements in the successful task completion by each participant were calculated using statistical methods.

Step 2: User task attempt rates were measured by recording the number of attempts each participant made to complete each task. An attempt was defined as a sequence of activities from the start to the end of an automotive UI use case scenario made on the touchscreen or haptic buttons that would result in completing the assigned task. The results from both trials were analysed to check whether any difference exists between them. Once completed, the improvement by each participant in the task attempt was calculated using statistical methods.

Step 3: The task efficiency was measured using the number of successful completions of a given task over the number of attempts made to that task by participants.

The feedback record and analysis of participants' usability responses were carried out using the measurement process described in Section 3.4.6.2.

6.5 Results of the Learnability Measurement

Table 21 shows the results of the number of successfully completed HMI tasks and number of attempts made to complete each successful task along with the efficiency measurement of all tasks. Results demonstrate that, in terms of CAUI solution, participants completed fewer tasks in the first evaluation compared to the second, i.e., the mean number of successfully completed tasks were lower in the first evaluation ($Mean=24.03$) compared to the second ($Mean=29.76$). However, participants made more attempts to complete each successful task in the first evaluation than the second; i.e., mean values of task attempts against successful task were higher in the first evaluation ($Mean= 44.38$) than the second ($Mean=34.55$). These differences appeared to be significant ($t(56)= -2.32$, $p <0.05$ & $t(56) =2.95$), $p<0.05$). The results also demonstrate that task efficiencies amongst all tasks were significantly improved in the second evaluation compared to the first ($p <0.005$). This confirms hypothesis ($H_{6.1}$), that the Indian drivers in this study would exhibit lower task efficiency in terms of 'learnability' with the new, culturally adapted automotive HMI system compared to a conventional system; however, their efficiency level would significantly improve with repeated exposure. Therefore, hypothesis H_6 is accepted for the evaluation studies.

Table 21: Results of the learnability measurement

Task	Task completed		Task attempts		Task efficiency	
	Phase 1	*Phase 2*	*Phase 1*	*Phase 2*	*Phase 1*	*Phase 1*
t1	35	35	43	35	0.81	1.00
t2	35	35	42	35	0.83	1.00
t3	12	28	29	36	0.41	0.78
t4	35	35	48	36	0.73	0.97
t5	32	34	38	35	0.84	0.97
t6	32	35	76	47	0.42	0.74
t7	35	35	43	35	0.81	1.00
t8	32	35	78	39	0.41	0.90
t9	22	31	58	37	0.38	0.84
t10	9	25	17	39	0.53	0.64
t11	18	31	65	47	0.28	0.66
t12	9	21	33	35	0.27	0.60
t13	19	32	34	37	0.56	0.86
t14	29	35	67	40	0.43	0.88
t15	35	35	43	35	0.81	1.00
t16	29	35	37	35	0.78	1.00
t17	16	23	57	33	0.28	0.70
t18	9	12	44	21	0.20	0.57
t19	15	27	45	30	0.33	0.90
t20	5	14	17	17	0.29	0.82
t21	3	9	10	16	0.30	0.56
t22	14	19	28	22	0.50	0.86
t23	35	35	40	35	0.88	1.00
t24	35	35	42	35	0.83	1.00
t25	27	35	51	40	0.53	0.88
t26	34	35	46	36	0.74	0.97
t27	34	35	66	40	0.52	0.88
t28	29	33	46	34	0.63	0.97
t29	23	34	44	40	0.52	0.85
Total	697	863	1287	1002	15.88	24.80
Mean	24.03	29.76	44.38	34.55	0.55	0.86
(SD)	(10.78)	(7.80)	(16.36)	(7.33)	(0.22)	(0.14)
t(df)	-2.32(56)		2.95(56)		-6.39(56)	
p	0.024*		0.005*		0.000**	

* = $p < 0.05$; ** = $p < 0.005$;

Table 22 summarises the distribution of improvement made by participants against each task category between the evaluations. The table ranks each task category based on recorded improvement. Figure 21 shows the graphical representation of the improvement data. On a category by category basis, the results show that participants made a bigger improvement on 'Bluetooth phone' related tasks, followed by 'Media player control' and GPS 'Navigation' related tasks. The results also show that participants made low improvement in 'Menu control' and 'Sound settings' related tasks. Participants completed *92.4%* and *85.7%* of the required tasks in the 'Menu control' and 'Sound settings' category with an attempt rate of *78.9%* and *69.3%* in the first evaluation. Therefore, the required improvement rate in the second evaluation was lower (Menu control = *7.6%* in task completion rate, *21.1%* in task attempt rate; Sound settings = *14.3%* in task completion rate, *30.7%* in task attempt rate) compared to other categories such as

'Bluetooth phone' (*33.8%* improvement required in task completion rate and *24.7%* improvement required in task attempt rate).

Table 22: Category by category task improvement rate amongst Indian users

Task Category	*No of successfully completed tasks*	*No of attempts made to complete task successful*	*Improvement between evaluations*		
			Efficiency rate	*% improvement*	*Rank*
Bluetooth Phone	50	50	1.00	28.2	1
Media Player Ctrl	18	23	0.78	22.1	2
Navigation	42	62	0.68	19.1	3
Radio Control	31	75	0.41	11.7	4
Menu Control	8	23	0.35	9.8	5
Sound Settings	17	52	0.32	9.2	6

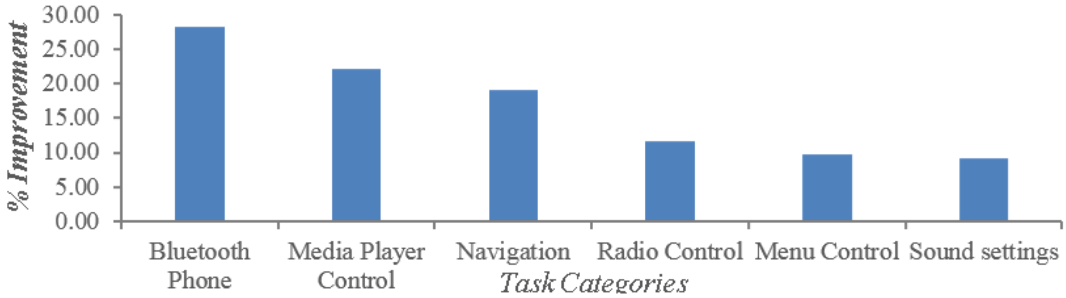


Figure 21: Improvement rate (%) per task category

6.6 *Results of the Usability Measurement*

Table 23 summarises the distribution between the CAUI and non-CAUI features on all 'usability' factors including 'Satisfaction'. The results demonstrate that the mean scores of CAUI features (all summated features) in all usability factors were higher than those of the non-CAUI HMI. Comparing the mean scores using the t-test for equal variances confirms that significant differences exist between non-CAUI and CAUI features for 'Usefulness', 'Ease of learning' and 'Satisfaction' ($p<0.005$). This confirms the hypothesis (H_7) that the Indian drivers in this study would exhibit higher levels of satisfaction towards culturally adapted automotive HMI solution once they gained an understanding of the system compared to the non-adapted solution. Data reliability shows Cronbach's Alpha over *0.70* in all factors, indicating good reliability (Nunally, 1978).

Table 23: Results of the Usability survey

Usability factors	*Solution features*		*t(df)*	*p*	*Cronbach's Alpha (α)*	
	Non-CAUI	*CAUI*			*Non-CAUI*	*CAUI*
Usefulness	1.58	2.55	-5.12(74)	0.00002*	0.889	0.760
Ease of Use	2.00	2.37	-2.21(74)	0.02972	0.735	0.714
Ease of learning	1.82	2.45	-3.61(74)	0.00056*	0.766	0.761
Satisfaction	1.61	2.50	4.54(74)	0.00002*	0.916	0.897

* *P < 0.005*;

The results also confirm that CAUI features have a positive influence on user behaviour intention, which in turn have the positive satisfaction towards an overall CAUI solution. The results of participants' behavioural intention, i.e., their intention to use CAUI features during driving as well as confidence towards CAUI solution are shown in Figure 22. The results show that *62.85%* participants intend to use CAUI feature settings all the time during their journeys while *34.28%* participants intend to use some of the CAUI features during a journey and only *2.85%* participants do not wish to use any of the CAUI features. Participants also show that there were, indeed, different levels of liking for the implemented CAUI features. The results demonstrate that *77%* of the participants have confidence towards CAUI solution and believed that such solution would improve their driving efficiency and make it more pleasurable. The results show that, participants intend to use 'Help function' the most and 'Information density adjustment' the least (Figure 23).

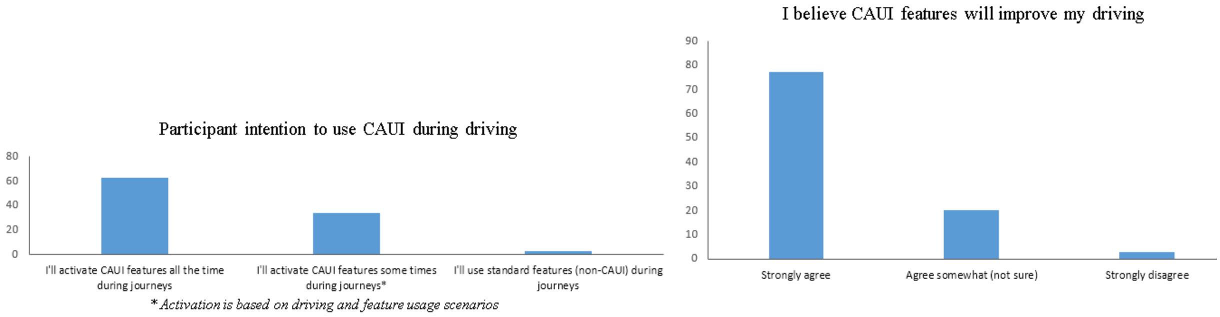


Figure 22: Participants behavioural intention (intention use & system confidence)

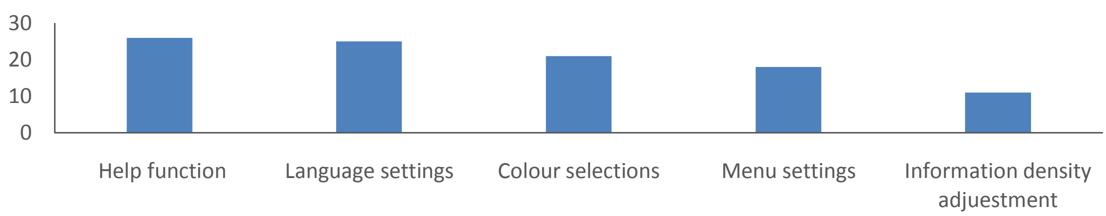


Figure 23: List of CAUI features participants intend to use most

6.7 Summary of the Findings and Discussions

The CAUI application study assessed Indian drivers' comprehension and satisfaction with respect to culturally adapted HMI design. The results showed a preference for the culturally adapted automotive HMI system if the Indian drivers in this study were offered a choice between this and the non-adapted system. The results from the 'learnability' evaluation confirmed that user adaptation levels towards the CAUI solution improved significantly in the second phase of the evaluation compared to the first ($P<0.005$). Thus, concludes that user task performance is affected both by the presence of a task and level of familiarity with the system. The Indian participants in the application study were new to CAUI applications and were not able to complete tasks faster in the first' learnability' evaluation. They made more attempts and errors to complete each task compared to the known conventional solution. However, their satisfaction level grew as they became familiar with CAUI features, needed fewer attempts to complete UI tasks and made fewer errors. This indicates that repeated exposure to the culturally adapted HMI solution enabled participants to be more efficient in terms of task completion. Thus, it can be concluded that task completion performance improvement over the repeated use of the system demonstrates that 'learnability' of the solution was good. This conclusion is supported by the system 'learnability' results (task completed $(p) = 0.024$, $p <0.05$; task attempts $(p) = 0.005; p <0.05$; task efficiencies $(p) = 0.000$, $p <0.005$), which significantly improved for the adapted solution between the evaluations.

Participants' responses to the usability survey for the CAUI and non-CAUI systems were also good. When analysed through t-test, the difference in usability factors between the solutions, was shown to be statistically significant in the majority of comparisons. This also held true for 'Usefulness' ($0.97, P<0.005$), 'Ease of learning' ($0.63, P<0.005$) and 'Satisfaction' ($0.89, P<0.005$). Thus, it can be concluded that the Indian participants in this study were more satisfied with the culturally adapted automotive solution once they gained an understanding of the system compared to the non-adapted solution. This, therefore, provides an overall high level of confidence that variation in the survey responses and task efficiency scores reflects how these participants perceive the 'learnability' and usability of a culturally adapted automotive HMI system.

The study demonstrates that Indian drivers intend to use the CAUI solution and associated features during their journeys if such features exist. The result appears to suggest a greater degree of confidence towards the solution.

Although Indian participants in this study were new to CAUI applications and made more attempts and encountered problems to complete UI tasks compared to a known conventional HMI system in the initial 'learnability' evaluation, they however, showed good interest towards accepting new technology, as the same number of participants returned to take part in the second 'learnability' evaluation as well as the usability survey (note: participant attendance was voluntary). This is, perhaps, no surprise because according to Table 18 in Section 5.7.1, it can be hypothesised that Indian participants in this study were 'Long-Term Oriented' as per Hofstede's cultural dimensions. Thus, being a long term culture, Indian participants would be expected to show perseverance and patience towards new technology (Coventry *et al*, 2004), and enjoy trying new equipment (Hofstede, 2001).

6.8 Chapter Summary

This chapter detailed the findings and key conclusions from the application study. As part of the study, a culturally adapted HMI prototype solution was developed. The solution was a modification to an existing production system and designed to generate a technology demonstration together with an evaluation report for the sponsor company's product management. Thus to achieve GO/NO-GO for the detailed investigation for industrial application. The next stage of the project developed a user-centered study to evaluate the 'learnability' and usability of the conceptual CAUI prototype solution. The primary goal of the user study was to analyse drivers' attitudes towards a culturally adapted HMI solution versus non-adapted solution. Another goal was to generate underlying recommendations and guidance as to how such a solution can be adapted within the automotive HMI design community and product development strategy. As such, application study phase completed the validity of the research model in a real-time environment.

The next chapter will discuss key industrial outputs from this research and level of innovation this study has generated in order to validate the industrial application of knowledge.

7 INDUSTRIAL IMPACT

7.1 Chapter Overview

This chapter describes the key industrial outputs of the research project. Primarily, it describes why the supportive organisation sponsored the project, what were the deliverables of the project and current status of CAUI solution development within 'New Product Introduction' process. This chapter also shares some practical knowledge as a means of HMI design recommendations for automotive designers and usability engineers.

7.2 Implication for the Sponsoring Company

The supportive organisation's main objective in sponsoring this research was to increase awareness and understanding of the cultural influence in future vehicle HMI design projects. The aspiration was to determine the 'Product Attribute Leadership Strategies' (PALS – a means within automotive industries to set a strategy for the development of vehicle features and attributes) in future HMI, as such research into cultural adaptation to the design which will enhance product effectiveness in emerging markets (i.e., be the leader in HMI attribute in future vehicle JD Power Asia-specific survey). In view of this, the EngD project has made a positive contribution to the sponsoring company. The outcome of the study generated a successful technology concept demonstration for the product development and marketing management. The conclusions made by the study also allowed the establishment of HMI guidelines for design localisation to be incorporated in future model year vehicle programmes (2019 CY beyond). Further study to analyse and understand the cost implications and value analysis of a culturally adapted HMI solution are proposed with an advanced engineering research note.

The sponsoring company had 'product appeal' issues with their HMI solutions in mid-segment carlines. Their previous Model Year vehicles scored poorly in '2011 JD Power Asia Pacific' automotive survey (Figure 24). The identified weaknesses in design related to, lack of good display, lack of user-friendly display menus, lack of intuitive icons and button HMI, lack of legible fonts and selection of colours, and lack of Indian-centric UI features.

At the same time, the marketing team recognised that 'attractive HMI design and audio system' is among the top 5 reasons for purchasing a vehicle in India and south Asian markets. However, sponsoring company's vehicles lacked in this aspect in relation to the benchmarked vehicles. This led to the development of an HMI marketing vision that would mandate PALS attribute leadership in future cars. Furthermore, the PD team also identified that technologies and interfaces common to more developed markets have been introduced in India recently and to, many drivers for the first time. There is, therefore, a need to understand the new users who drive within that culture, which may bring new design requirements into the adoption curve. However, there is a lack of rules and tools available within the company to understand these new user requirements and use them to inspire HMI design localisation. To mitigate such challenges, three internal mega-theme research projects were initiated during 2011: quality and packaging of audio system improvement, test process improvement, and assessment of design localisation and user engagement in HMI development. This collaborative EngD research study project between the sponsoring company and WMG is part of the design localisation mega-theme project.

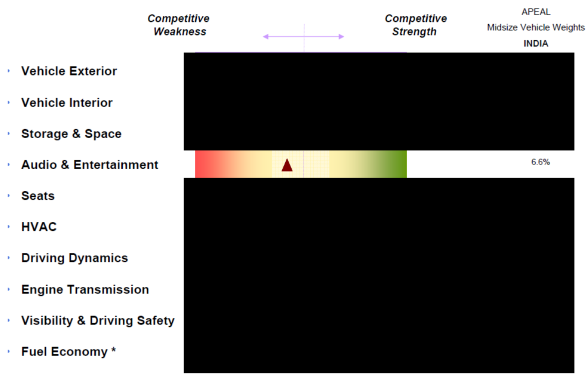


Figure 24: JD Power 2011 scores on sponsoring company's mid-size vehicles
(Implemented in report with sponsoring company's permission, not to be copied or referenced in future)
** HMI is part of the Audio & Entertainment category*

7.2.1 Project Deliverables

The key deliverable of the project was a recommendation document containing, the proposal of an architectural framework for HMI design localisation keeping automotive legislation and quality in place, together with future design rules and requirements for cultural adaptation. Figure 25 represents the overview of architectural pattern along with cultural components proposed to the company to generate a culturally adapted automotive UI solution. The sense of HMI culturalisation (a method of integrating culture and software localisation) is emphasised using the UI attributes such as ‘Content’, ‘Context’ and ‘Navigation’ of the graphical information architecture. The market specific customisation is achieved by configuring the software variables and constants within the data configuration file. Process for adapting display application for the local languages was implemented using separately locale-specific software (e.g., XML script) libraries and translation text (ASCII and Unicode) within information architecture. Application of architectural framework together with system functional requirements (both common and specific to a culture), generated a CAUI software application that can be marketed to a specific cultural region while keeping hardware abstraction and operating software services common in all regions. Thus, the solution provides a good amount of reusability. This solution was implemented in a mid-size production sedan vehicle and validated part of the project. The overview of the results is discussed in Chapter 6.

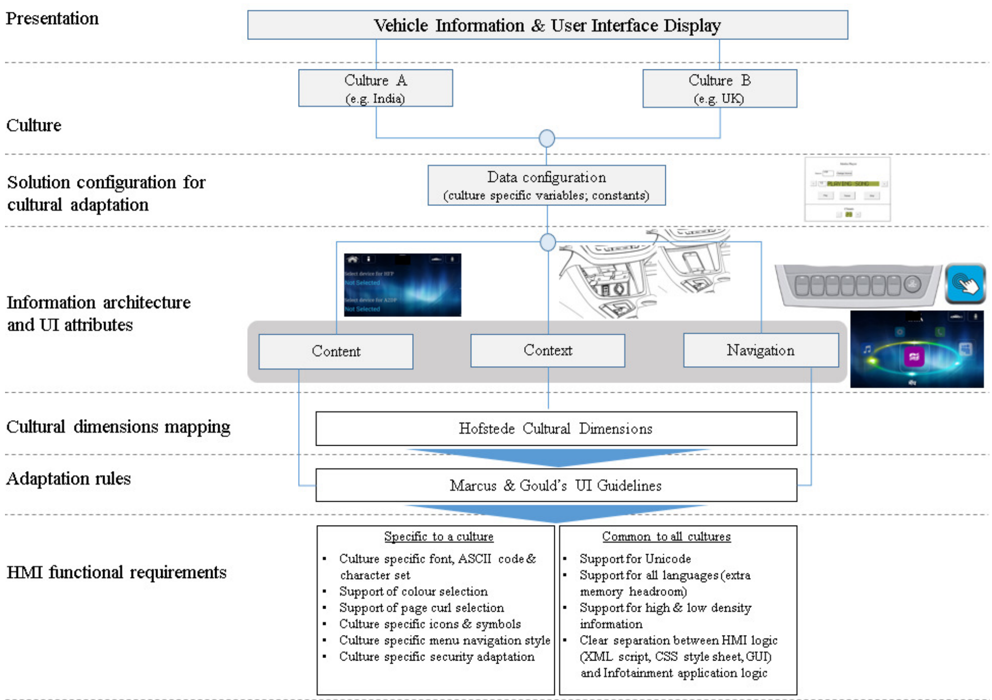


Figure 25: Overview of the proposed architectural framework
(Figure implemented in report with sponsoring company’s permission, not to be copied or reference in future)

An elaborate HMI design recommendation with a process for implementation also delivered to the sponsoring company’s design studio and product testing group. These documents will serve as the guidelines for future vehicle HMI attribute development and design sign-off. Table 24 shows an example of implicated design recommendations based on the successful test carried out during the research project (Chapter 4, 5, 6).

Mohd Hasni (2012) stated that, the density of information in GPS 'Navigational' direction influence user satisfaction in a high UAI culture. Although Indian participants in this research scored low in UAI (Chapter 5, Section 5.7.1), this study found that the information density and colourfulness of display influences Indian drivers, as such this project can corroborate Mohd Hasni's recommendations and stated implications for future HMI design localisation in India.

Table 24: Recommended design guidelines for sponsoring company's HMI design and testing group
(Table implemented in report with sponsoring company's permission)

UI attributes	*India*	*UK*
Context	Provide user help option to guide driver about how to use Infotainment and GPS Navigation functions.	User help can be an optional feature as long as the driver can activate or deactivate this feature.
	Provide direct error message in case of an Infotainment function malfunction. The message should clearly state what action should be carried by the driver to close error.	A supportive error message can be developed, provided this information does not overload the driver during driving and do not cause a distraction.
Content	Display content and structure can be designed in a way that facilitates distinctive layout, style, user-friendliness between male and female driver.	Provide content personalisation so that information and feature can be removed or added based on driver choice and his/her need.
	Provide language translation option for each Infotainment and GPS Navigation functions including voice guidance.	There is no requirement to provide a language translation feature within UI design.
	Provide low-density information on Infotainment and GPS Navigation functions for user ease of learning.	Information density can be according to system functional requirements and use cases.
Navigation	Open access navigation style can be implemented with a variety of menu structures.	Use close and limited navigation menu structure for the driver.
	The ambiguous menu navigation path is acceptable provided there is an option to come back to the main menu.	Consistent menu navigation path should be maintained throughout the UI.
	Information can be unstructured, however, abbreviated text should be avoided.	Information should be structured, but can be unrestricted to achieve limited navigation structures.
Presentation	Masculine colour schemes and colour pattern related to religious belief should be provided. Dark colours e.g., black, dark grey etc. should be avoided.	Masculine and feminine both colour selections can be an optional feature.
	Use national and religious symbol wherever possible for local user attention and satisfaction.	Use a universal design image to supplement textual information.
Interaction	Develop short keys for quick interaction with Infotainment and GPS Navigation functions.	Develop short keys for quick interaction with Infotainment and GPS Navigation functions.
Generic	Add a configuration software data file in HMI presentation layers so that each vehicle can be configured for cultural regions. The configuration file can be set for a cultural region during the manufacturing process (in VC – Vehicle Configuration stages).	

A cross-cultural design configuration tool has been developed as part of the project. The configuration using 'Enterprise Architect' model is able to determine the cultural differences within the use cases related to Infotainment functions (e.g., Media player language selection type, GPS Navigation background colour selection etc.). The tool (Figure 26) allows the measurement of numerical values such as the number of colour palette, the intensity of display colour, density of information in displays etc. in relation to a specific Infotainment function display screen. Designers can use the tool to communicate with HMI suppliers to cascade graphical requirements and fine tune any UI attributes during initial prototype developments. Once the design is frozen these values are used within the system architecture configuration file (Figure 25) to customise HMI display screen for the vehicle's target market.

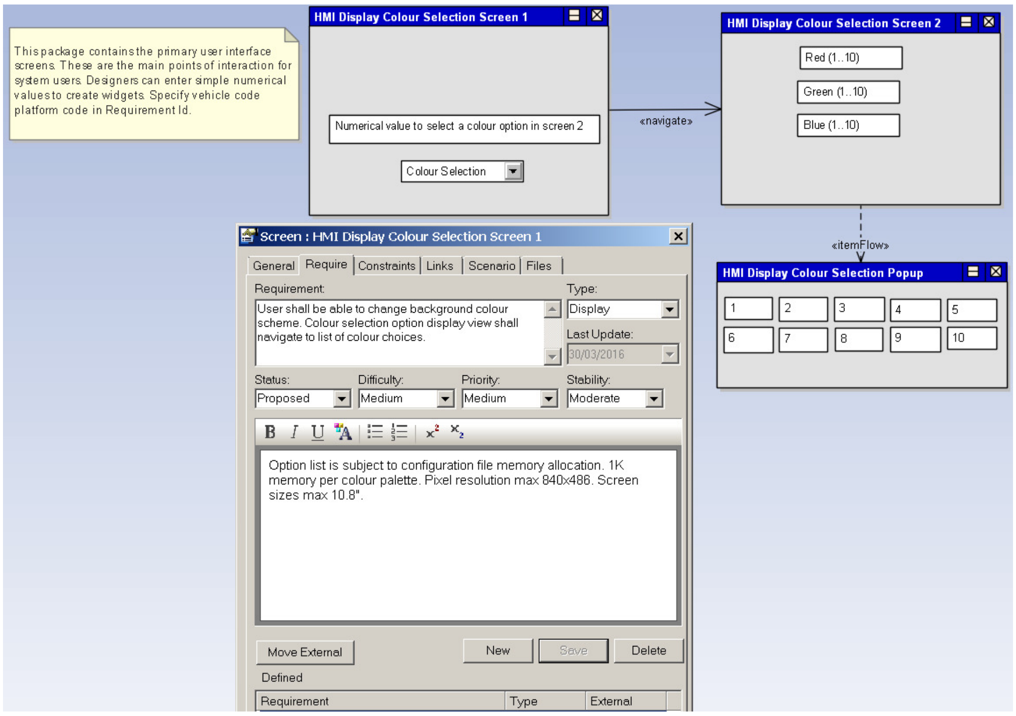


Figure 26: Screenshot of the configuration modelling tool

(Figure implemented in report with sponsoring company's permission, not to be copied or reference in future)

7.2.2 CAUI Current Status - Research Development Process

Figure 27 shows how the project is integrated into the sponsoring company's vehicle development process together with current production status. The research project conformed to the four gates of 'Research Development Process' (RDP) in sponsoring company's technology introduction scheme. RDP is designed to transfer an outcome of the technology research to a vehicle program in a defect-free manner. The adherence to the process reduces the risk of new technology introduction to a level where it is acceptable to incorporate in new vehicle development program (NPI-New Product Introduction). The project passed 'Concept Demonstration' <CD> gate and an internal advanced engineering research note specifying the definition of CAUI concept and implication for sponsoring company's future HMI development and marketing strategies were defined in order to proceed to 'Application Readiness' <AR> gate. Both concept and strategy document were reviewed during a gateway meeting by the Advanced Engineering head, Vehicle Line Director and passenger car supply chain representative to ensure commercial input. The review committee approved the concept and agreed to incorporate CAUI feature set in future mini hatchback and sedan derivative vehicles. As a result of the review committee decision, the project has been taken out of RDP process and placed into future vehicle product development process (NPI - <MOD> gate) and several activities to introduce CAUI features within the target vehicle platform are devised (each planned deliverable between DR0 – SOS is described in Figure 27). Furthermore, recommendations made by the study were taken as a basis for incremental design changes for all legacy vehicle platforms. The architectural pattern was also taken as a basis for future Informatics system design prerequisite guidelines for all future vehicles. The CAUI features were also implemented in several auto-show concept vehicles for the user and media review.

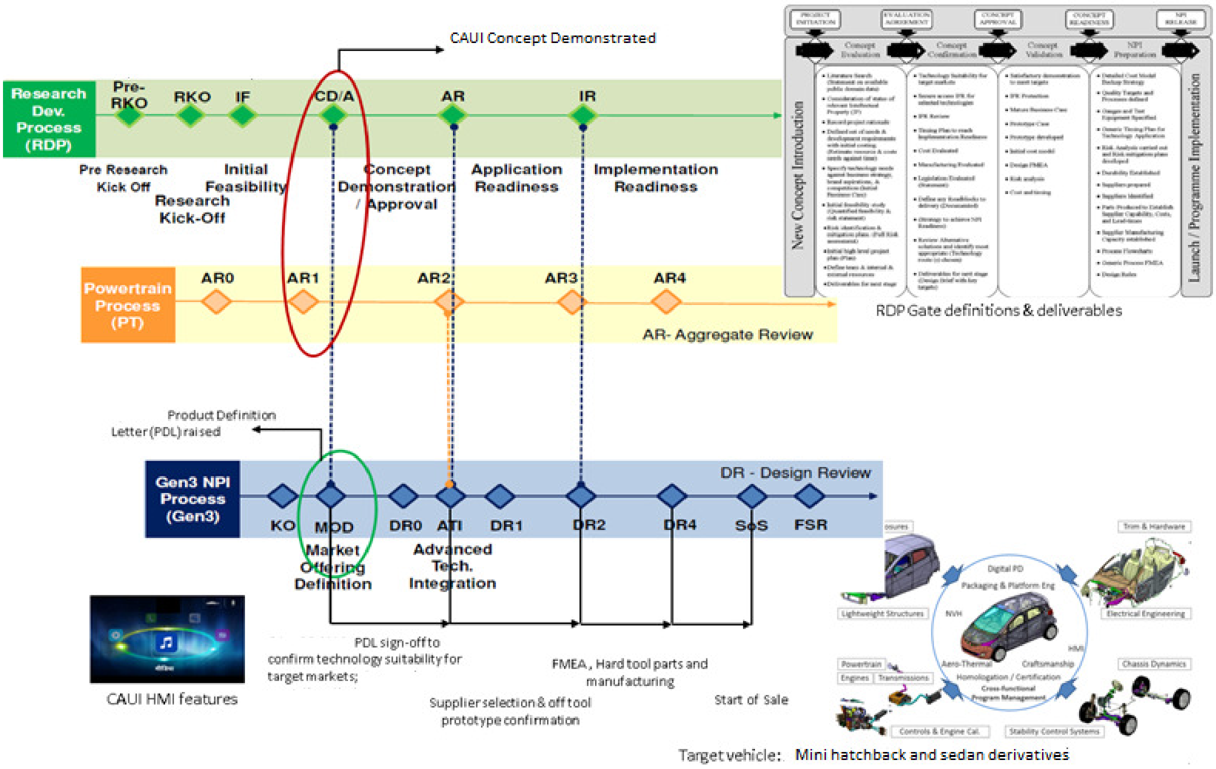


Figure 27: Current project status of CAUI in RDP/NPI definition

(Figure implemented in report with sponsoring company's permission, not to be copied or referenced in future)

7.3 *Implication for Wider Automotive Industries*

This study along with few other cross-cultural researches (e.g., Mohd Hasni, 2012; Young *et al*, 2011) contributes to theoretical development through theory testing and by providing insights into less explored areas of cross-cultural knowledge for vehicle manufacturers, suppliers, and academics. This knowledge includes the use of a cultural model to analyse automotive users' values, cultural influence in automotive user behaviour, and the role of culture in HMI system acceptance. This research study identifies some core values which automotive users attach when deciding their preferences for HMI design. These values, thus, should be used in communicating future automotive HMI design strategies.

7.3.1 Way Forward with Culturally Adapted HMI

Although the application of CAUI is aimed at the sponsoring organisation's industrial objective, the path towards a cultural adaptation of vehicle HMI could be widened and applied to wider automotive industries, particularly during the concept design and prototype development stages (e.g., <CD> - <DRO> gate in Figure 27 or similar new technology/product introduction scheme). In this regard, intercultural HCI design management process (Schoper & Heimgartner, 2013), simplified method of culturally-oriented design (Heimgartner, 2012) and Global web design guidelines (Marcus & Gould, 2000; 2015) has practical use in designing cross-cultural automotive HMI. Having analysed these processes and used web interface design recommendations across user-centered studies, a potential automotive HMI design management framework have emerged following the finding of the report. The proposed framework represents (Figure 28) an approach for automotive designers and usability engineers by combining the best practices and recommendations of current HCI design process with elements of cross-cultural management. It integrates knowledge about cultural differences in automotive 'new technology development' process. This analysis is deduced according to the findings described in Chapter 4, 5 and 6.

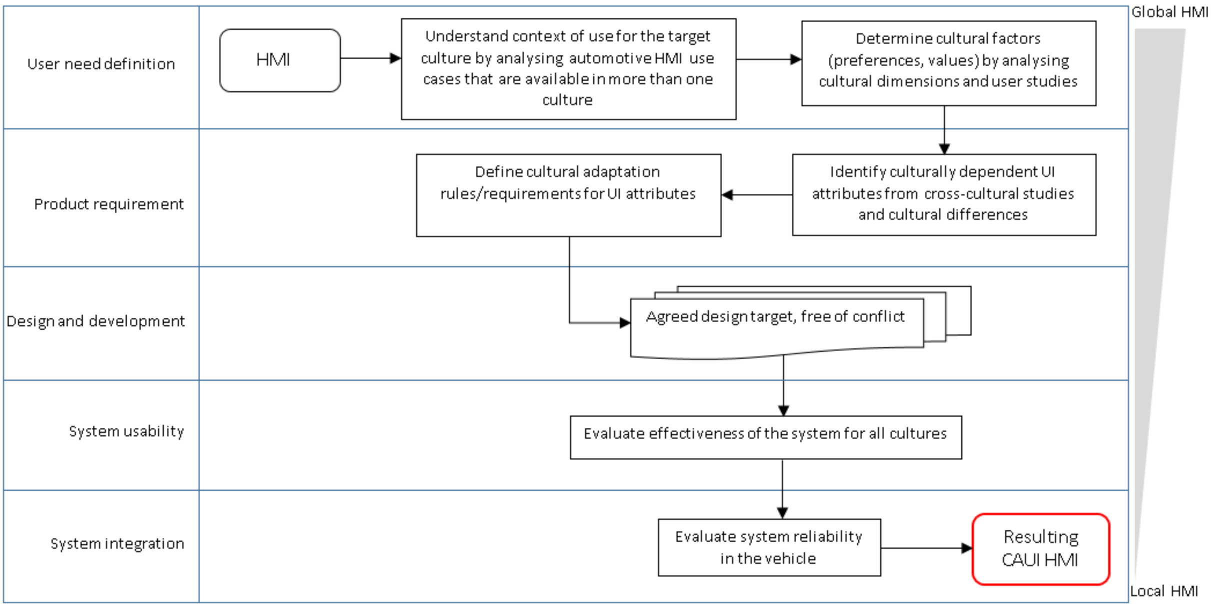


Figure 28: Cross cultural HMI design management framework
(Adapted from Schoper & Heimgartner, 2013 and Heimgartner, 2012)

This study has shown how a global HMI can be customised for Indian cultural context and their target automotive audiences. Future researchers can exploit the CAUI concept prototype further to extend this design for other cultural settings, for example, in the case of a Chinese or South African cultural context. As such, Table 25 summarises the list of steps future designers or researchers can follow to develop a CAUI prototype for another cultural setting.

Table 25: Extension of CAUI application in future prototype development

Design Parameters	*Tasks*
Development of cultural setting	Identify cultural groups or audiences that requires a ‘Culturally Adapted User Interface’ solution.
	Define testing strategies for the identified cultural setting.
Human factors in UI design	Apply cultural model (e.g., Hofstede, Hull, Trompenaar etc.) and their rules to identify whether target cultural setting has any similarity or differences with existing HMI base design.
Application of design principles	Identify best suitable design principles (e.g., Marcus & Gould, CUI, Cultural finger print etc.) for the target design modifications.
	Identify UI attributes that require a cultural application or adaptation.
	Develop functional prototype level requirements for Graphical User Interface and architectural settings.
Development of Prototype	Ensure that there is a clear separation between presentation, application and embedded system of the HMI architecture.
	To achieve the best possible outcome on separation, a solution configuration methodology (Figure 25) should be considered, particularly in the area of software data configuration.

7.3.2 Key Points for HMI developers and Usability Engineers

Automotive HMI developers and usability engineers should keep in mind that:

- Cultural dimensions can correlate with certain countries. For example, high ‘Power Distance’, ‘Long-Term Orientation’, and ‘Collectivism’ correlate with Indian culture. In comparison, ‘Individualism’ and ‘Short-Term Orientation’ correlate with UK culture.
- Cultural models (e.g., Hofstede) can make a measurable contribution to understand regional users’ values they attach when selecting the automotive HMI features. The dimensions can also allow designers to measure HMI system usability and user satisfaction towards the system. However, automotive designers should exercise caution when using ‘Hofstede VSM’, as this research has shown that there are inconsistencies amongst derived theoretical dimensions and actual field study results.
- Marcus and Gould’s web interface design recommendations can work as a preliminary assessment tool for cultural user requirements in automotive design.
- Measurement of users’ cultural values can greatly improve user needs analysis in the automotive HMI design process. The assessment can be carried out during early prototype development phases.
- The findings manifest that there are clear patterns of challenges among Indian automotive users’ usability performances and their task efficiencies when using a conventional HMI system with high information decoding features. Thus, the potential benefit of a culturally adapted HMI system should not be ignored.
- HMI Features are not synonymous with Infotainment functionality. In fact, this research shows, HMI features necessary in one country may not be important in another. As such, instead of adding different features for each country, cross-cultural research discovers which features can be whittled down to one solution and which are necessary country-specific variants, thus helping towards the development of cross-cultural system architecture.
- Finally, an innovative option in future HMI system to differentiate a design would be through usability and localised functionality. A comprehensive matrix that includes cross-cultural design, ergonomics, end-user perception and usability study provides a basis for creative thinking that is grounded in reliable data.

7.4 Chapter Summary

This chapter has given accounts of the key industrial outputs and contribution against research aim and objectives. It provides a holistic view of the industrial application of the culturally adapted solution. This research project has made a novel contribution to the sponsoring company's HMI development strategies. It has also shown how adaptation strategies can be applied to wider automotive industries. This information will provide vehicle manufacturers, especially sponsoring company and its HMI suppliers with a much-needed understanding of how automotive HMI solutions can be improved (and possibly custom configured) to appeal to a very wide range of end users in different regions of the world. The next chapter will discuss the knowledge contribution within the context of the research examined in previous chapters and assess whether research objectives has been met.

8 DISCUSSIONS

8.1 Chapter Overview

The research conducted as part of this study explores how a cultural model can be utilised in automotive HMI design with knowledge gained from cultural theories and methodologies developed by HCI researchers. The research question and research objectives underlying this project are defined in Section 1.4. This chapter will assess each research objective within the context of the research examined in Chapters 4-6. Based on this, major conclusions about the research problem are emphasised. This evaluation allows the extent to which the study has answered the overall research question to be determined. Further, an analysis with regard to the innovation and application contained within the study will be conveyed. Finally, this chapter will present the limitations of the research.

8.2 Generic Discussion on Research Findings

The research examined the application of Hofstede cultural model into several aspects of automotive HMI design: (1) assessing the cultural values of the automotive users from cultural groups; (2) assessing the cultural relationship in HMI usability; (3) alignment of the cultural dimension into HMI feature design requirements; (4) assessing user preferences towards HMI design and features; (5) assessing culturally adapted HMI system acceptance amongst Indian automotive users. All studies completed in the research showed that Hofstede's model can be used to explain the cultural differences in automotive users' values and their HMI usability performances. The research also showed that adapted web interface recommendations by Marcus and Gould work well across the cultural groups sampled in the studies which do point to differences in automotive user attitudes towards HMI design and feature preferences. Furthermore, the results clearly demonstrate a preference for the culturally adapted automotive HMI solution, if the automotive users in this study were offered a choice between this and the non-adapted solution.

8.3 *Discussion on Specific Findings*

8.3.1 Cultural Value Assessment

This research could not statistically verify all the expected results as per Hofstede's cultural theories (note: in this study, cultural dimension differences amongst two groups are only valid if calculated results demonstrated a statistically significant outcome ($p<0.05$)). For example, in Chapter 4, the study shows both Indian and UK samples are high 'Power Distance'. They are both 'Individualist' and low in 'Uncertainty Avoidance'. These results contradict cultural indices provided by Hofstede; only 'Masculinity' index presented a pattern similar to Hofstede's theory (according to Hofstede's original data (2001; 2015), India scores more in 'Masculinity' than the UK; the UK scores more in 'Individualism' than India; India scores slightly more in 'Uncertainty Avoidance' than the UK). When related hypotheses were tested with higher samples in Chapter 5, results demonstrated some consistencies with Hofstede's cultural theories. For example, hypothesis $H_{1.1}$ (The Indian cultural group will display higher 'Power Distance' compared to the UK cultural group), $H_{1.2}$ (The UK cultural group will display higher 'Individualism' compared to the Indian cultural group) and $H_{1.5}$ (The Indian cultural group will display higher 'Long-Term Orientation' compared to the UK cultural group) presented a pattern similar to Hofstede's theories. However, the 'Masculinity' and 'Uncertainty Avoidance' indices presented a pattern contrary to the expected direction (according to Hofstede data, India scores slightly higher on 'Uncertainty Avoidance' compared to the UK).

It is interesting to note that the 'Masculinity' and 'Long-Term Orientation' indices demonstrated contradictory patterns amongst user studies. For example, in Chapter 4, the Indian sample was significantly 'Masculine' compared to the UK; however, in Chapter 5, both cultural samples were equally 'Masculine'. Furthermore, in Chapter 4, the Indian sample scored negatively (LTO= *-10.0002*) in the 'Long-Term Orientation' index, thus making them a 'Short-Term Oriented' culture according to Hofstede's definition. However, in Chapter 5, in the same cultural group, this time with the higher sample sizes scored positively (LTO= *+91.33*) thus making them a 'Long-Term Oriented' society. As discussed in section 4.8, these differences are not considered to be detrimental to any of the studies described in Chapter 4 and 5. All studies ensured sampling equivalence during the design of sample selection specification, particularly in the area of demography. All studies also ensured that levels of prior technology and driving knowhow are equal in both groups and provided training prior to any experiments. As such, participant selection procedures helped consistent and valid VSM08 questionnaire responses. Furthermore, to alleviate variations in cultural dimension rankings in relation to Hofstede's original data, VSM tests were carried out twice with the same sample specification and scales for the same cultural groups (India and the UK). This, therefore, provides an overall high level of confidence that variation in the VSM08 responses and scores reflects how these participants perceive the cultural value.

Although the inconsistencies in cultural value results (Chapter 4 and 5) are difficult to analyse, there may be several explanations: firstly, previous research in cross-cultural studies demonstrates that replication of 'cultural values' using Hofstede's VSM for different cultural groups received different results in terms of cultural dimensions (e.g., Heuer *et al*, 1999; Hoppe, 1990; Fernandez *et al*, 1997; Merritt, 2000). Moreover, studies that measured Hofstede's national dimension using different scales also reported variations in country rankings in relation to his original data (Fernandez *et al*, 1997). Secondly, although at surface level national cultures exhibit stability, diversity exists in cultural values among members of any given national culture. Therefore, the Indian and UK participants' cultural diversity may have played a role in the differences between actual and expected results. In fact, previous research analysis suggests that India has no clear positions on three of Hofstede's dimensions because the Indian culture is highly complex and pluralistic, containing seemingly inconsistent and contradictory orientations (Arora, 2011; Shrivastava & Shrivastava, 2012). Third, although culture is considered to be stable, it has been 20 years since Hofstede's data was collected. India and the UK, in particular, have undergone major societal and economic changes in the last few decades. Thus, these changes may not be reflected in the original Hofstede data and relevant theories. Therefore, while this study confirms that cultural models can help automotive designers to make a culturally generated interface design, this may not always be the only route to understanding the needs of regional automotive users. Differences may also exist due to technological availability, user know-how, physical environment and societal influence (Khan *et al*, 2016).

8.3.2 Validity of VSM

The results of the VSM analysis completed in this research produced inconsistent outcomes. This raises a concern about its validity and applicability to obtain useful cultural information between regional groups in automotive HMI design projects. One possible explanation for such inconsistent results could be due to the selection of samples and their characteristics in these studies. Participants in value comparison studies (Chapter 4 and 5) were selected from academic institutions in India and the UK. Therefore, it is feasible that the cause of such inconsistency may be due to the relative youthfulness and lack of professional experience of the university students used for the study. However, Hofstede's VSM should have been agile to cater to a wide range of participants to measure cultural differences between groups. In interpreting these results it is recommended that automotive designers should examine the VSM with various types of participants of different ages and professions to check the consistency of the outcomes to allay any concerns that the model is working.

8.3.3 Cultural Aspects of HMI Usability

The research started with an implicit assumption that driver use of the vehicle HMI system is constant between cultures. As such, design attributes that are appropriate for the UK is also appropriate for India. However the literature review confirmed opposite; what may seem to be a good usability design in one culture may not be perceived as such in other cultures (Wallace & Yu, 2009). This led to an assumption that there may be some elements within the automotive HMI design, that are culturally sensitive and these elements influence the driver usability of the system. This assumption found to be true during the analysis of user-centered study in Chapter 4, where cultural influence is shown as one of the root-causes for differences in user usability performances, particularly in 'Ease of learning' and 'Satisfaction' towards a conventional HMI system (amongst UK and Indian participants – Figure 11 and 12). The results show a high degree of challenges for Indian users with high information and high task load related Infotainment functions such as GPS 'Navigation', Bluetooth phone etc. (Figure 13). Therefore, it can be concluded that user performance towards HMI tasks varied amongst cultural groups in this research study. The result also clarifies that the cultural dimensions correlate with some of the factors that make up usability (the correlation between 'Uncertainty Avoidance' and 'Usefulness', 'Ease of use', 'Ease of learning', 'Satisfaction' for both cultural groups). On the weak side, this study provided evidence that drivers' cultural dimensions influence how they use an automotive HMI system; however, how much they influence according to culture is not clear from the study. This study only considered whether a correlation exists between culture and automotive HMI usability. Therefore, further study is required to identify methods of calculation of correlation severity between culture and automotive HMI usability.

8.3.4 Analysis of Kano Model

Although numerous studies have employed the Kano method, it is not without weaknesses. This study experienced a practical problem with the model's definition of 'Attractive' requirements during Kano survey questionnaire development as well as analysis of survey responses. For example, the original model defines 'Attractive' if the requirement elicits customer satisfaction when fulfilled, but does not cause dissatisfaction when not fulfilled (Matzler & Hinterhuber, 1998; Berger *et al*, 1993;Mikulic & Prebezac, 2011). However, further studies revealed that some researchers interpreted the definition as "are present or have sufficient performance", but do not cause dissatisfaction when "not present or their performance is insufficient" (Tontini & Silveira, 2007, p486). Interpreting the latter definition implies that, the Kano model provides similar classification regardless of whether features are fulfilled or not fulfilled in terms of presence or defined performance. These contradictory definitions caused confusion during participants' responses and to the analyses of some response categories. Previous research also reports this issue (Mikulic & Prebezac, 2011). To alleviate the confusion, this research followed the original Kano model definition defined by Berger *et al,* (1993). Further study to define an easier and more interpretable definition may provide many more differences on regional automotive users' HMI feature preferences.

8.3.5 Driver Attitude towards Culturally Adapted HMI Solution

The goal of the CAUI evaluation (Chapter 6) was to understand Indian drivers' attitude towards the interaction with localised display HMI features and their likelihood of use during driving in India. The findings indicate that cultural adaptation has advantages over a conventional non-adapted HMI system. The finding also suggests that Indian drivers intend to use the CAUI solution to improve their driving and have confidence towards it. Furthermore, findings also show the benefit of the user configurable approach by mapping proven cross-cultural UI guidelines (Marcus & Gould) as functional requirements. Conventional approaches to localisation would have presented participants with ‘Hindi’ version, i.e., simply translating the relevant display information into the language of the exported country (in this study, India). However, this would have increased the risk of ethnocentrism, which is the tendency to evaluate local user and cultures according to assumptions and ideas originating in one’s own culture and represents a normal phase in the development of every discipline (Fauchex, 1976). Ethnocentrism could have led to the improper generalisation of user requirements (Coventry *et al*, 2004), for this research project. Therefore, adaptations of Marcus & Gould recommendations are justified for the development of CAUI solution.

Literature review shows, culture has an influence on user behaviour through its manifestations of values, heroes, rituals, symbols and colours (Luna & Gupta, 2001). This held true for this study. For example, in this study non-CAUI, HMI carried dark and black dominated colours, which are seen as elegant in Europe according to Rossger (2014). However, participants in this research study found dark or black colours are unsatisfactory, as they communicated, black is non-auspicious (religious belief) and in general, dark colours make them claustrophobic (ref. data summarised from participants ‘any other comments’ responses in application study questionnaires). This substantiates the idea that satisfaction and preferences differ amongst regional automotive users and that culturally adapted automotive HMI solution which offers user configuration of cultural dependent UI features can resolve these differences. Therefore, the study found a valid argument that cultural adaptation of automotive HMI can play a significant role in user acceptance of future HMI design for the global automotive industry. The study has also provided further support to the idea that designing for Indian cultures requires, “developing evaluation methods and metrics capable of capturing relevant dimensions of the interaction” and, importance to the user experience rather than technology (Coventry *et al*, 2004, p42).

The results of the study are in sync with previous HCI studies and confirmed that users’ learning improves over a series of repeated exposures. Contrary to McCarthy *et al,* (2004), who state that users adapt quickly to unexpected design layout, the current study observed that the user adoption level increases over repeated exposures. The study also illustrated that more exposures led to a decreased task attempt rate indicating user learning occurred and improved system effectiveness in terms of user manipulation of the new system.

8.4 Validation of Research Question

The research conducted during this study has been used to build upon the theoretical foundation in order to be able to answer the following research question.

"*How can a cultural model be applied in the development of automotive Human Machine Interfaces and used to design culturally adapted solution for user acceptance and satisfaction?"*

The key elements of the research question relate to driver acceptance and satisfaction of culturally adapted HMI solution (CAUI). Acceptance in this study is defined as a demonstrable willingness by a user group to employ (Dillon & Morris, 1996) or accept (Regan *et al*, 2014), CAUI solution for the driving tasks is it designed to support and, user attitude to incorporate such solution in his/her driving situations (Adell, 2009). Satisfaction, on the other hand, is a construct of usability which is defined as the drivers, comfort with and positive attitudes towards the use (ISO 9241-11), of CAUI solution.

Although literature review showed different ways of measuring acceptance for Information Technology (IT), e.g., Technology Acceptance Model – TAM (Davis, 1989), UTAT Model (e.g., Adell, 2009), Technology Readiness (Parasuraman, 2000) etc., there was no conclusive information as to which measurement model is ideal for cross-cultural automotive HMI user acceptance. As such, the measurement of examining what influences the acceptance from regional driver's perspective for this study is defined as: the CAUI solution must satisfy the usability needs of the Indian driver during his/her actual use of the Infotainment functions in a driving scenario (the second and fifth acceptance definition category in Table 1, Section 1.4.1). This was evaluated during the application test, where a conventional HMI is configured to suit Indian participant's needs and expectations regarding HMI and Infotainment functions. Specifically, driver's 'learnability', 'usability' and intention to use CAUI features was examined. CAUI solution was the outcome of previous comparison studies in this research (Chapter 4 and 5). The solution used Marcus & Gould's cultural web interface guidelines as well as Hofstede's cultural model as a basis for requirement engineering in its architecture pattern and development process. This proved that cultural adaptation in HMI design is possible in the first place because cultural differences in automotive HMI can be recognised and measured quantitatively using usability metrics.

The application test result highlighted the importance of cultural adaptation and found benefits from the use of CAUI HMI after subjective evaluation by Indian participants, which was not predicted before. The key challenged being the assumption that lack of expertise with new vehicle technologies is major deterrents to CAUI solution acceptance by Indian drivers. The findings show, although few fell into these categories during 1st user evaluation, but their intention to use CAUI features to perform HMI display operations remained high throughout the test and their learnability improved significantly by the time they completed 2nd evaluation (Table 21, Section 6.5), which in turn have the positive satisfaction towards an overall CAUI HMI compared to conventional one. This proved that once an Indian driver realises the benefits associated with using CAUI HMI, “previous expertise are not intrinsic barriers” (Coventry *et al*, 2004, p41), to solution acceptance.

According to Regan *et al*, (2014), for any technology solution, intention to use and actual usage, increases system learning and influence user acceptance. The application test findings of the research corroborated such emphasis, which shows that 63% Indian participant intend to keep all CAUI features active during their driving in India compared to 3% participants who would not use them. This proves that regardless of how pleasant CAUI features are, Indian participants found them useful and intend to use them during a journey. This outcome synchronises with Adell’s (2009) proposed definition of acceptance: Indian automotive users would incorporate the CAUI HMI solution in his/her driving if such solution is provided by vehicle manufacturers in the vehicle. Consequently, the study has achieved its sets research objectives and answered the research question.

8.5 Innovation Statement

The conceptual design of culturally adapted HMI, its architecture pattern, development approach and design tool defined in Chapter 7 is new to the sponsoring organisation, as such, it constitutes the main innovation to result from this research. Furthermore, Section 7.3.1 describes a framework of interrelated work packages (WP) towards cultural adaptation of HMI for automotive designers and usability engineers. The framework is developed to reduce the time and efforts between cultural considerations in the design and seeing the consequences of considerations. These WPs fits the demand of cultural oriented UI design and usability projects that require a greater level of understanding the relationship between user cultural background and technology adoption.

The further innovation of the study has been to extract information regarding cross-cultural customer needs and preferences in HMI design using the Kano survey for decision support in future automotive technology development. There has been no previous research about the utilisation of Kano model within the cultural context of automotive HMI design. Based on the results and their detailed assessment (Chapter 5), the research provides several recommendations in Chapter 7 for sponsoring company's designers to deal with the issue of culture and usability in HMI design. Recommendations and process adaptation methods are, therefore, suitable for automotive manufacturers who intend to expand their products beyond traditional Western markets to the emerging markets. The study results can also function as an educational process for product development organisations whose strategic leadership is unaware of the cultural impact in HMI design as well as vehicle platform development strategies.

The outcomes of this study contribute to the knowledge of usability engineering, user-driven requirement engineering and integration of user cultural values into the design and culturally adapted prototype development. Therefore, the value of this research is that it broadens the understanding of the issues currently facing the automotive HMI design community, especially those designers who undertake work in cultures other than their own. Furthermore, this research indicates that, although the application of the study is aimed at the automotive sector, the approach could easily be applied to other industries and markets.

The development process and outcome of the studies were appreciated in several knowledge dissemination publication journals. The assessment of the peer review of SAE journal is included in Appendix X, which shows high scores for the innovation aspect of the research study.

8.6 Limitations of the Research

Although it was believed that this research study makes a good contribution to furthering cross-cultural research in automotive HMI design, it is not without its limitations.

- The first limitation of this research is the number of participants within each cultural group used for comparison study described in Chapter 4. Hofstede (2008) recommends that, for statistical purposes, an ideal size for a homogeneous participating sample would be between 30-50; this study used less than the recommended criteria. Previous automotive cross-cultural studies also experienced similar limitation due to comparative sample selection between countries (Mohd Hasni, 2012). As a result, some of the cultural value analysis may exhibit a shortfall on data encoding. In fact, a larger sample size result would have incorporated further experience into the application prototype and provided additional evidence to support assertions (Kennerley *et al*, 1996).
- The second limitation relates to the HMI samples selected for study in Chapter 5. These samples were adapted from existing production vehicles, ensuring that the intended context of the use was preserved during the evaluation. This approach, however, reduced control over individual factors by not presenting the participant with opposing levels for each requirement (e.g., high and low levels of structured information). Future studies in this area may benefit from the creation of bespoke HMI prototypes to test the relationship between each of the requirements and user preference.
- The third limitation relates to use of the Kano model for study in Chapter 5. There are various research reports on the use of this model in product/service industries. However, there has been no such model to use within the cultural context of automotive HMI design. Due to this, there is a lack of comparison sources for both data and methods. For example, the findings in Chapter 5 could not conclude whether culture has any relation to user HMI design preferences as per Kano responses. Therefore, further study is required to model the

relationship between the user's cultural background and his/her automotive HMI features preferences.

- The fourth limitation relates to the cross-cultural comparability in Kano survey responses in Chapter 5. Although research administrators were consulted, the Kano model features questions remained a complex engineering questionnaire for the participants in this study. The surveys and data collection were also a long process. Research engineer needed to write two questions for each of the 17 feature requirements specified in Table 16 (Section 5.3) for six categories of HMI display functions (Radio, Media player, GPS Navigation, Phone, Menu control & Settings). Thus, doubling the number of questions compared to a non-Kano type survey. Furthermore, each of the Kano questions utilised Marcus & Gould's (2000; 2015) recommended terminology without making any changes or interpretation; making it a complex engineering questionnaire as opposed to a simple feature survey by the user. Therefore, some respondents may have found the questionnaire frustrating and difficult to interpret, particularly, those participants whose first language is not English. As such, participant's comprehension concerning survey questions may have influenced the lack of consistent responses, e.g., each of the Indian participants, may have interpreted and understood the same question in vastly different ways (Brady, 1985). This could be addressed in future studies by focusing on few HMI functions than all of them and creating more pilot studies upfront to design an easily understandable questionnaire for non-English speaking and non-technical participants.
- The fifth limitation relates to CAUI prototype integration in application study (Chapter 6). The integrated CAUI was available in the rudimentary form, which falls short of a fully operational vehicle solution compared to the non-CAUI. This approach may have reduced Indian users' performance and subjective usability ratings. In fact, a more aesthetically appealing integrated design would have, created more positive emotions and received higher usability ratings (Sauer & Sonderegger, 2009) for CAUI solution. Furthermore, a high fidelity prototype solution would have accelerated Indian users' learnability during evaluations. As such, future studies will benefit from a more aesthetically appealing high fidelity integrated CAUI solution.
- The sixth limitation relates to cross-cultural research approach on all comparison and evaluation studies. These studies took existing production HMI solutions and conducted field

research, to see if they can be applied to a new setting or population (Godina & McCoy, 2000). Furthermore, in all studies, Indian culture was compared according to the dimensions defined by cultural theories, survey questionnaires while research engineer remained outside of the physical evaluation sessions (both in India and the UK). As such, this research complied with 'etic' approach[1]. Although this approach is common to foreign researchers who are outside of India (Sinha & Kumar, 2004), and allows comparison across context and population, and the development of cross-cultural concept (Morris *et al*, 1999), however, according to Geertz (1983), survey data are often dismissed because, "researchers remained at a distance from respondents, potentially insensitive to how respondents were affected by their questions" (quoted in Morris *et al*, 1999, p783). Therefore, this study agrees with Sinha & Kumar's (2004) assertion that future cross-cultural automotive HMI studies should utilise multi-method approach, "integrating both etics and emics[2]" (p100) in order to understand Indian culture comprehensively.

- Finally, a commonly held limitation of cross-cultural studies is that the results may not generalise to other products or cultures. This is also true for this study. The developed prototype and evaluation analysis requires further examination in different cultural regions and cultural settings before its universality can be proclaimed.

However, while these shortfalls commonly associated with cross-cultural research they do not dilute the importance and novelty of the research and its contribution. Indeed, understanding and experimenting user behaviour in the global consumer culture is a dynamic and incremental process with each step of experiment raising new research questions. This research along with a study by Mohd Hasni (2012) opens the process of understanding regional automotive HMI and GPS 'Navigation' users, meeting their true needs and making their HMI user experience more enjoyable.

8.7 Chapter Summary

This chapter brought together all the key themes of the research and discussed them together in relation to the research question. The key areas of research that were undertaken to fulfil the research objectives and hypotheses have allowed this research question to be answered within the identified limitations of the studies. Fulfilling the research question has meant that this research study has developed and applied innovation and made a contribution to knowledge in the field of automotive HMI design as well as advanced technology development strategies. This work can now be consolidated by drawing conclusions on the key findings and recommendations arising from this research study can be made in the final chapter.

[2] In a cross-cultural research, an ‘emic’ approach refers to field study carried out and data obtain from the perspective and words of research participants, i.e., how local people think and behave, while ‘etic’ approach obtains data from the perspective of an observer, i.e., uses as its starting point from theories, hypothesis, and concepts from outside of the setting being studied (Godina & McCoy, 2000). This study only assessed definition of these approaches and in-depth process analysis is not investigated.

9 CONCLUSIONS

9.1 Chapter Overview

This final chapter presents the overall conclusions of the research findings. It offers suggestions for future research.

9.2 Key Conclusions from Research Findings

- The innovation report demonstrates the value of cross-cultural user-centered research as a way to clarify the benefit of culturally adapted HMI design strategies. The findings provide clear support for the hypothesis that Indian automotive users are different from UK users in terms of their values, design preferences, and HMI task performances. Therefore, this study agrees with Young *et al's* (2011) assertion that, these differences will have implications for one-size-fits-all automotive HMI trend, for the appeal, system acceptance, and usability.

- The study concludes that the development of automotive HMI design requires the understanding of the needs and context of users who uses it. In this situation, designers should be engaged with target cultures directly in order to better understand regional drivers and co-design or co-create new design opportunities that generate mutual value for all stakeholders and obtain requirements early in the technology development process when all possibilities are open.

- Based on these conclusions, a number of implications for automotive product managers and strategist surface. First, they should be aware that automotive buyers from different cultural backgrounds respond and process HMI features and attributes differently as users. Furthermore, it appears that cultural groups' defined value differently. Therefore, cross-cultural research is a valuable tool for automotive manufacturers trying to determine product viability.

- This research concludes the use of Hofstede's cultural dimensions for future research in user cultural value comparison between two regional groups. His theory was useful as a framework to summarise and understand automotive users' values, attitudes, and behaviours.

- It was, however, not sufficient to anticipate which cultural factors influence automotive users' HMI feature preferences, as the research discovered the cultural values were not consistent across cultural groups. Therefore, it remains a point for further study to analyse cultural differences in values and orientation across drivers from cultural groups.

- This research shows good evidence of a link between cultural dimensions and HMI system usability. It illustrates that system 'Ease of use' and 'Ease of learning' has an influence on the overall Indian user satisfaction of the HMI system and concludes that the layout and complexity of an automotive HMI screen influence user from High 'Power Distance' and 'Masculine' cultures. As such, 'learnability' is a possible factor in determining the perceived usability of an automotive HMI system. Therefore, the goal of making easy to learn should be set as a key design strategy regardless of system complexities.

- The research shows that high workload tasks influence vehicle user HMI task efficiencies in India compared to low workload tasks (according to Jordan (1998), the workload is a measurement of the efficiency of driver mental capacities to perform tasks while driving with no mistakes or error). These outcomes are also influenced by participants' knowledge about personal consumer electronics. Therefore, cultural influence may not be the only factor in differences in user performance of automotive HMI system usability observed across regions and countries.

- This research identifies differences in HMI feature preferences amongst Indian and UK users using a Kano-style user survey. This model was very effective for the research to understand Indian and UK users' preferences in HMI design. It provides a clear illustration of the difference between the user needs of the two cultural groups as shown in Figure 17.

- The study concludes that Marcus and Gould's culturally-generated web interface guidelines can be applied as a basis for future automotive HMI design requirement engineering. The study recommends that automotive HMI designers need to pay greater attention to culturally biased user requirements when designing for a region where these cultural values are prevalent. Particular consideration should be given to the usability and 'learnability' characteristics of drivers from different regions.

- The contextual investigation of this research confirms that Indian drivers would exhibit higher levels of satisfaction towards a culturally adapted automotive HMI solution once they gain an understanding of the applications compared to the non-adapted solution. However, Chapter 8, Section 8.3.1 emphasises that a common design may not meet the needs of all Indian drivers due to the existence of multiple sub-cultures within India. Thus, development of a culturally configurable prototype solution is justified in this research, and should be seen as an important step in the design of future systems.

9.3 Recommendation for Future Work

This study provides rich results that have the potential to be exploited further and developed into new areas for research. One such area is the usage of appropriate industrial tools for automotive manufacturers to obtain information regarding cultural differences and the relationship with users' preferences towards future HMI design. As discussed in Chapter 8, an in-depth cross-cultural study with more inclusive cultural regions may clarify some of the complex findings pertaining to the culture and user behaviour towards automotive HMI design. In this regard, a qualitative methodology such as in-depth interviews or polychronic time orientation across cultures (Hall, 1983) or socioeconomic classification (Blishen, 1958; Duncan, 1961; Nam, 1963) could complement the study results further. Furthermore, many standard cross-cultural measurement tools used in previous HCI studies such as cultural finger print, utility theory, etc., have yet to be validated within the automotive HMI domain. Validating any of these tools in cross-cultural settings would make a significant contribution to the field of future automotive HMI design.

Another major area for future study will be to expand this research by adding more countries to the existing analysis. The sample used in this research attempted to gain the widest representation possible; however, it was limited in scope to those countries where collaborations could be found. Thus, the list of possible additions of cultural regions in future cross-cultural automotive HMI research is vast and any addition would certainly enhance the understanding of cross-cultural HMI design. Moreover, using a different or wider participating demographic as opposed to only students (in Chapter 4 and 5), as this research project used, would make the findings more generalisable for automotive designers. For example, different participation groups which include participants from computer peripheral design knowledge, more female participants, and different ages could provide further insight of cultural influence in future HMI design.

A difficulty in this research was to establish a clear relationship between users' cultural background and their HMI design preferences. Therefore, further research is needed on the conceptualisation and operationalisation of automotive user behaviour as well as on the relationship between their perceived usability, cultural influence, and design preferences. Therefore, a much broader question regarding the type of development process automotive manufacturers can use to deal with the issue of merging cultural influence and usability (e.g., Culturability) for future HMI solutions may need to be investigated.

Finally, this study only utilised and validated Hofstede's national dimensions for understanding automotive users' values. However, as discussed in Chapter 2, Section 2.4.2, other cultural models are available to HCI practitioners such as Trompenaars Onion model (1993; 1994; 1996) and Hall's cultural factors (1959). These models should be explored for future automotive HMI design utilisation. The validity and applicability of other models may provide a clarification for automotive HMI designers and usability engineers as to which model is appropriate in automotive industries and further insight into the cultural influence in regional users' preferences.

9.4 Concluding Remarks

The research undertaken in this study utilises knowledge of cultural theories and best practices developed by HCI specialists to deal with cultural influence in the design and assesses their usability in automotive Human Machine Interface (HMI). In doing so, this research has developed cross-cultural user-centered work packages for automotive manufacturers and suppliers. This study makes a novel contribution to the body of knowledge in automotive technology development strategies. It is shown that cultural differences do exist and can be documented in the area of HMI design and user needs analysis. This innovation report is not an exhaustive consideration of cultural models in automotive HMI and, as discussed in the previous sections, future research can build on the work presented from this in many ways.

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APPENDICES

Appendix I   BSREC Confirmation of Approval

15th July 2014

Warwick Medical School

PRIVATE
Mr Tawid Khan

Dear Tawid,

Study Title and BSREC Reference: *A Study of Cultural Models in Automotive HMI: Framework for Accommodating Cultural Influence* REGO-2014-775

Thank you for submitting your revisions to the above-named project to the University of Warwick's Biomedical and Scientific Research Ethics Sub-Committee for approval.

I am pleased to confirm that approval is granted and your study may commence.

Please keep a copy of the signed version of this letter with your study documentation.

Yours sincerely

P.P. Graham Hewitt

David Davies
Chair
Biomedical and Scientific
Research Ethics Sub-Committee

Biomedical and Scientific
Research Ethics Sub-Committee
A010 Medical School Building
Warwick Medical School,
Coventry, CV4 7AL.
Tel: 02476-151875
Email: BSREC@Warwick.ac.uk

Appendix II HMI Usability and Satisfaction Questionnaire

A. Usability Questions

Please indicate your degree of agreement or disagreement with following statement. Please read the User Satisafction Evaluation (USE) and System Usefulness Scale manual for further understanding. Circle the number that best describes your opinion.

Statements	*Strongly agree*				*Strongly disagree*
Overall, I am satisfied with how easy it is to use this system	1	2	3	4	5
It was simple to use this system	1	2	3	4	5
I can effectively complete my work using this system	1	2	3	4	5
I am able to complete my work quickly using this system	1	2	3	4	5
I am able to efficiently complete my work using this system	1	2	3	4	5
I feel comfortable using this system	1	2	3	4	5
It was easy to learn to use this system	1	2	3	4	5
I believe I became productive quickly using this system	1	2	3	4	5
The system gives error messages that clearly tell me how to fix problems	1	2	3	4	5
Whenever I make a mistake using the system, I recover easily and quickly	1	2	3	4	5
The information (such as online help, on-screen messages, and other documentation) provided with this system is clear	1	2	3	4	5
It is easy to find the information I needed	1	2	3	4	5
The information provided for the system is easy to understand	1	2	3	4	5
The information is effective in helping me complete the tasks and scenarios	1	2	3	4	5
The organization of information on the system screens is clear	1	2	3	4	5
The interface of this system is pleasant	1	2	3	4	5
I like using the interface of this system	1	2	3	4	5
This system has all the functions and capabilities I expect it to have	1	2	3	4	5
Overall, I am satisfied with this system	1	2	3	4	5

B. Satisfaction Questions

Please indicate your degree of satisfactio following statement.Please read the User Satisafction Evaluation (USE) and System Usefulness Scale manual for further understanding. Circle the number that best describes your opinion.

Statement Category	*Statement*	*-ve*						*+ve*
Overall reaction to the software		*Terrible*	1	2	3	4	5	*Wonderful*
		Difficult	1	2	3	4	5	*Easy*
		Frustrating	1	2	3	4	5	*Satisfying*
		Inadequate power	1	2	3	4	5	*Adequate*
		Dull	1	2	3	4	5	*Stimulating*
		Rigid	1	2	3	4	5	*Flexible*
Screen	Reading characters on the screen	*Difficult*	1	2	3	4	5	*Easy*
	Highlighting simplifies task	*Not at all*	1	2	3	4	5	*Very much*
	Organization of information	*Confusing*	1	2	3	4	5	*Very clear*
	Sequence of screens	*Confusing*	1	2	3	4	5	*Very clear*
Terminology and system information	Use of terms throughout system	*Inconsistent*	1	2	3	4	5	*Consistent*
	Terminology related to task	*Never*	1	2	3	4	5	*Always*
	Position of messages on screen	*Inconsistent*	1	2	3	4	5	*Consistent*
	Prompts for input	*Confusing*	1	2	3	4	5	*Clear*
	System informs about its progress	*Never*	1	2	3	4	5	*Always*
	Error messages	*Unhelpful*	1	2	3	4	5	*Helpful*
Learning	Learning to operate the system	*Difficult*	1	2	3	4	5	*Easy*
	Exploring new features by trial and error	*Difficult*	1	2	3	4	5	*Easy*
	Remembering names and use of commands	*Difficult*	1	2	3	4	5	*Easy*
	Performing tasks is straightforward	*Never*	1	2	3	4	5	*Always*
	Help messages on the screen	*Unhelpful*	1	2	3	4	5	*Helpful*
	Supplemental reference materials	*Confusing*	1	2	3	4	5	*Clear*
System capabilities	System speed	*Too slow*	1	2	3	4	5	*Fast*
	system reliability	*Unreliable*	1	2	3	4	5	*Reliable*
	System tends to be	*Noisy*	1	2	3	4	5	*Quite*
	Correcting your mistakes	*Difficult*	1	2	3	4	5	*Easy*
	Designed for all levels of users	*Never*	1	2	3	4	5	*Always*

Appendix III Cultural Value Survey Data

A. UK cultural group

	PDI				*IDV*				*MAS*				*UAI*				*LTO*			
	Q7	*Q2*	*Q23*	*Q26*	*Q4*	*Q1*	*Q9*	*Q6*	*Q5*	*Q3*	*Q8*	*Q10*	*Q20*	*Q16*	*Q24*	*Q27*	*Q18*	*Q15*	*Q28*	*Q25*
	2	2	4	4	1	2	2	3	1	2	2	3	2	3	3	3	2	1	2	2
	2	3	3	3	1	4	2	3	2	4	2	3	1	2	2	3	2	3	2	2
	2	1	2	3	2	1	4	1	2	2	4	2	1	4	1	5	2	3	2	3
	1	2	4	2	1	1	3	1	2	2	1	3	2	2	2	3	3	1	2	1
	1	1	3	3	2	1	3	1	1	1	2	3	2	3	1	3	2	1	3	2
	2	2	3	4	1	1	2	2	1	2	1	2	1	3	1	2	3	2	3	2
	3	2	4	2	4	1	3	2	3	3	3	3	4	3	2	3	2	2	2	2
	2	3	3	4	2	2	3	2	2	2	2	3	2	3	3	3	2	3	2	2
	2	2	3	1	2	1	2	1	2	1	2	2	1	3	2	2	3	1	2	2
Mean	1.89	2	3.22	2.89	1.78	1.56	2.67	1.78	1.78	2.11	2.11	2.67	1.78	2.89	1.89	3	2.33	1.89	2.22	2
SD	0.6	0.71	0.67	1.05	0.97	1.01	0.71	0.83	0.67	0.93	0.93	0.5	0.97	0.6	0.78	0.87	0.5	0.93	0.44	0.5

B. Indian cultural group

	PDI				*IDV*				*MAS*				*UAI*				*LTO*			
	Q7	*Q2*	*Q23*	*Q26*	*Q4*	*Q1*	*Q9*	*Q6*	*Q5*	*Q3*	*Q8*	*Q10*	*Q20*	*Q16*	*Q24*	*Q27*	*Q18*	*Q15*	*Q28*	*Q25*
	1	4	3	1	1	1	2	1	1	2	1	2	2	4	4	3	1	2	1	4
	2	2	2	1	1	1	1	1	2	2	3	2	1	2	5	3	2	2	1	2
	1	2	2	4	1	2	3	1	2	1	3	2	2	2	4	2	1	1	1	2
	2	3	4	4	1	1	2	1	2	2	2	1	2	4	2	5	2	3	2	4
	2	2	5	2	2	2	2	2	2	1	2	1	2	3	4	3	3	1	2	2
	2	1	4	3	1	1	3	2	2	1	2	1	1	4	3	2	2	1	2	1
	1	2	2	1	3	2	2	2	2	1	3	1	2	4	4	1	2	3	2	1
	3	3	4	3	2	2	3	2	3	2	3	2	2	4	2	3	2	2	2	1
	3	2	4	3	3	1	4	2	2	1	5	1	1	4	3	3	1	2	3	1
Mean	1.89	2.33	3.33	2.44	1.67	1.44	2.44	1.56	2	1.44	2.67	1.44	1.67	3.44	3.44	2.78	1.78	1.89	1.78	2
SD	0.78	0.87	1.12	1.24	0.87	0.53	0.88	0.53	0.5	0.53	1.12	0.53	0.5	0.88	1.01	1.09	0.67	0.78	0.67	1.22

Appendix IV Usability Data

A. UK cultural group

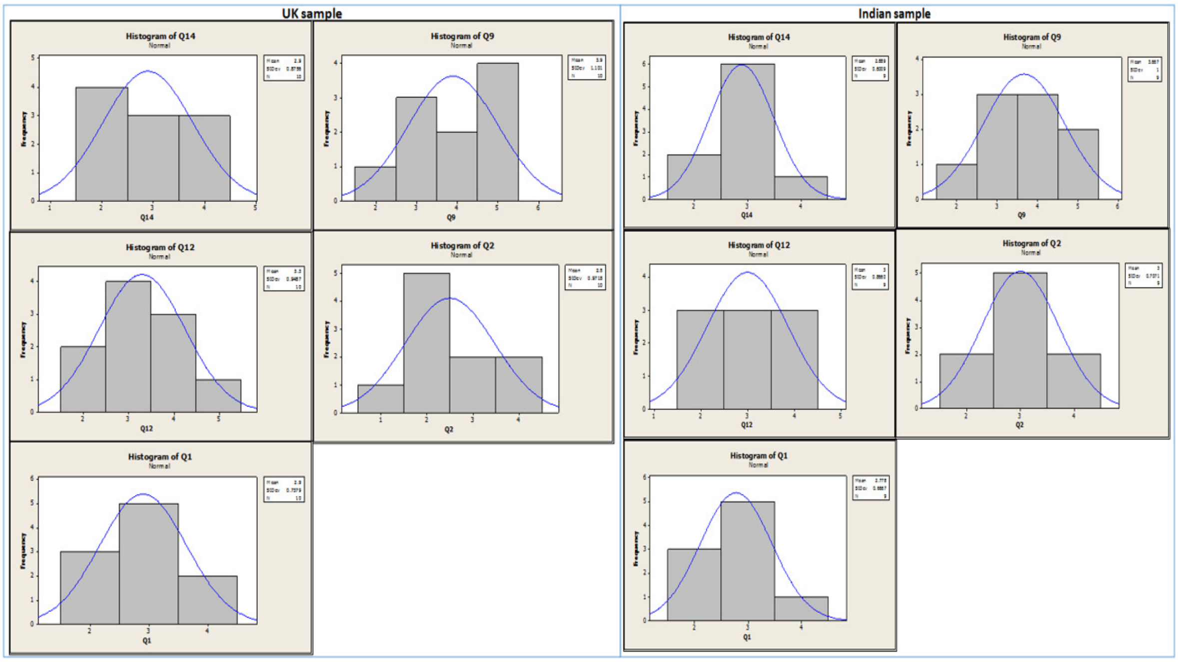
	Usefulness					*Ease of Use*					*Ease of Learning*			*Satisfaction*			
P1	3	3	2	2	2	3	2	3	3	3	2	3	3	4	3	4	5
P2	4	2	2	3	2	3	3	2	4	2	2	4	3	3	4	3	3
P3	2	2	3	2	2	2	2	4	2	4	2	2	2	3	4	3	2
P4	2	3	2	2	2	3	2	3	3	2	3	3	2	4	3	3	4
P5	4	4	3	3	1	3	3	5	4	2	3	4	3	4	3	4	4
P6	3	3	4	3	2	2	2	4	4	3	3	2	3	4	4	3	4
P7	4	4	4	2	3	4	4	5	3	3	3	5	3	4	4	3	4
P8	4	4	5	3	1	3	2	5	3	4	4	4	4	3	4	3	4
P9	1	3	2	2	2	2	1	3	2	2	2	2	2	4	3	3	3
P10	4	4	4	3	2	4	4	5	5	4	3	4	4	4	4	2	3
Total	31	32	31	25	19	29	25	39	33	29	27	33	29	37	36	31	36
Mean	3.1	3.2	3.1	2.5	1.9	2.9	2.5	3.9	3.3	2.9	2.7	3.3	2.9	3.7	3.6	3.1	3.6
Count	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SD	1.1	0.79	1.1	0.53	0.57	0.74	0.97	1.1	0.95	0.88	0.67	1.1	0.74	0.48	0.52	0.57	0.84

B. Indian cultural group

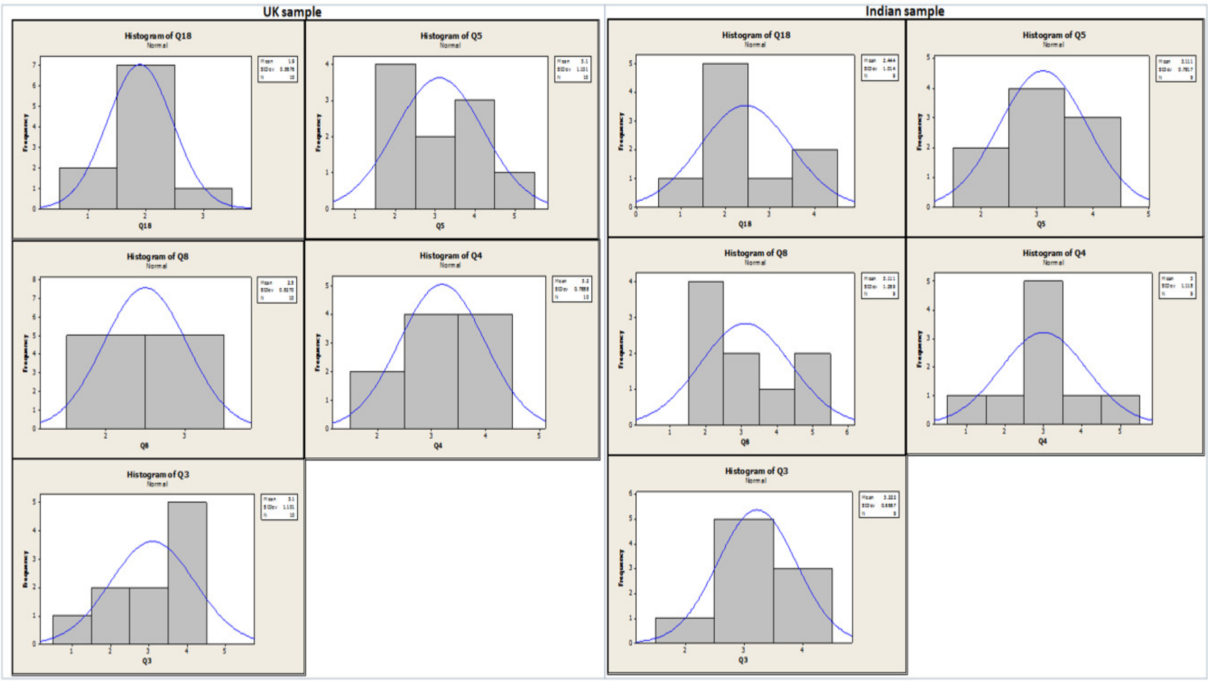
	Usefulness					*Ease of Use*					*Ease of Learning*			*Satisfaction*			
P1	4	3	2	5	4	3	3	4	3	4	3	2	2	4	3	3	2
P2	3	3	4	2	2	2	2	3	2	3	2	2	1	2	2	3	2
P3	3	1	4	2	4	3	3	5	3	2	2	2	1	3	3	3	2
P4	3	3	3	2	1	2	3	2	2	2	3	1	2	1	2	3	1
P5	4	5	3	5	3	4	4	3	4	3	3	3	3	4	5	2	1
P6	2	3	3	3	2	2	2	4	2	3	3	3	2	2	3	3	2
P7	3	3	3	3	2	3	3	3	3	3	2	3	3	3	4	3	2
P8	3	4	2	4	2	3	4	5	4	3	3	3	4	4	4	3	2
P9	4	2	4	2	2	3	3	4	4	3	2	4	3	3	4	3	3
P10	3	3	3	3	2	2	3	3	3	2	3	2	2	3	3	3	2
Total	32	30	31	31	24	27	30	36	30	28	26	25	23	29	33	29	19
Mean	3.2	3	3.1	3.1	2.4	2.7	3	3.6	3	2.8	2.6	2.5	2.3	2.9	3.3	2.9	1.9
Count	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SD	0.63	1.05	0.7	1.19	0.9	0.67	0.66	0.97	0.82	0.63	0.52	0.85	0.94	0.99	0.94	0.31	0.56

Appendix V Distribution of Usability Survey Scores

A. Distribution of 'Ease of use' scores

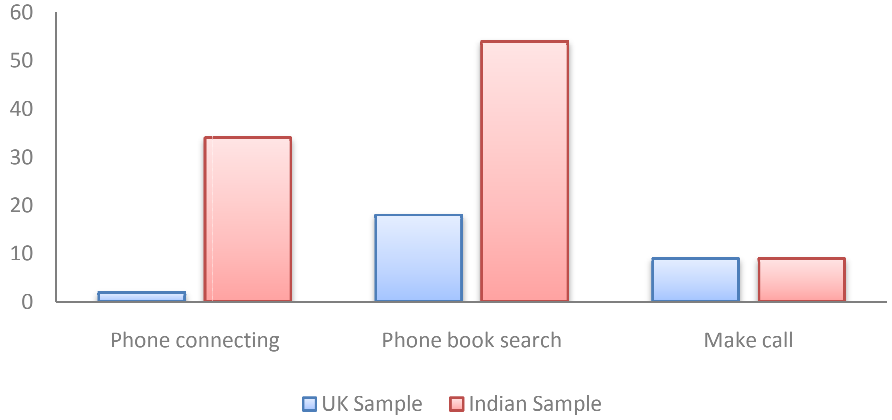


B. Distribution of 'Usefulness' scores



Appendix VI User Performance Data

A. Comparison of Phone tasks completion time between UK and Indian participants



B. Group score differences in overall performance factors

Performance factors	*Cultural sample*		*t-test*	*Significance*
	UK	*India*		
Mean Task completed (overall)	12.666	11.777	t=0.41023*(*p>0.05*)	Not Significant
Mean Task completion time (secs)	160.23	233.44	t=0.05665*(*p>0.05*)	Not Significant

Appendix VII Communication with ResearchAdministrator

From: mm.elec@coep.ac.in [mailto:mm.elec@coep.ac.in]
Sent: 25 March 2014 01:45
To: Tawhid Khan (TMETC Plc)
Subject: RE: Cross-Cultural usability study

Good Morning Mr. Khan

Went through the information provided. Few questions/requests :-

1) In the presentation on the first slide can you please use the full form of HMI.
2) Slide no.3 what does HUD, HDLF and NVH stand for. (The students are from electrical background and they wont know what these terms are - as these are common terms used by mech. engineers or people dealing with automotive design).
3) Do you expect the students to download the consent form sign it, scan and send it back to you??

Regards

Mrs. Meera Murali

Asst. Professor
Electrical Engg. Dept.
COE , Pune -05.

From: tawhid.khan@ta n>
Sent: Monday, March 24, 2014 6:28 PM
To: mm.elec@coep.ac.in
Cc: M.A.Williams.1@warwick.ac.uk
Subject: FW: Cross-Cultural usability study

Dear Madam,

As discussed last week I have now developed a survey questionnaire for the cross cultural usability study. Please review and give me your feedback. To understand the objectives and process of this study I have a developed few presentation slides, which details objectives of the study, process and outcome of the study. If you have any questions regarding questionnaire or objectives or process then do not hesitate to contact me.

I like to thank you for your kind help for facilitating this study. I am very grateful for your help.

Many Thanks and Kind Regards
Tawhid Khan
TATA Motors European Technical Centre Plc
University of Warwick, Coventry, CV4 7AL, UK

From: mm.elec@coep.ac.in [mailto:mm.elec@coep.ac.in]
Sent: 26 February 2014 05:12
To: Tawhid Khan (
Cc: Amancharla Naga [Specialist - Adv. Technology]; SURESH ARIKAPUDI [Divisional Manager (Development) , Pune CVBU , ERC - S]; M.A.Williams.1@warwick.ac.uk
Subject: RE: Cross-Cultural usability study

Good Morning Mr. Khan

Went thru your mail. July should not be a problem as the semester would have begun by then, but as you require the students for 3 days I will have to get official permission from the Head of the department. Secondly I would like to know the number of students you might need.

Regards

Mrs. Meera Murali

Asst. Professor
Electrical Engg. Dept.
COE , Pune -05.

Appendix VIII Kano Questionnaire on HMI Feature Prefernces

We want to assess your preferences for car Human-Machine-Interface (HMI) features. To do that we will ask you pairs of multiple-choice questions. The first question in each pair asks how you feel if your car HMI included a particular feature to an extent greater than you have experienced during evaluation stages. The second questions, ask how would you feel if you had less or none of the feature.

You should place a √ or highlight in the column that corresponds with your answer to each question. It is important that you answer both "functional" and "dysfucntional" part for each questions. Each question relates to the image of the screen. Please do not discuss with your answer with others and respond indenpently. We thank you for your cooperation.

	Statement	*I like it*	*It Must be that way*	*I'm Neutral*	*I Can Live with it*	*I Dislike it*
	These questions relates to 'Phone Display screen'					
Functional	How would you feel if vehicle display interface system provided highly structured information access for the system	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system provided images of local hero or leader in the display content	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system provided minimal menu options	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system provided descriptive text on each menu options	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system provided many menu options	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system provided abbreviated text on each menu options	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system provided icon on each menu options	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system provided quick results for limited tasks (limited button press options)	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system allowed user exploration (challenge user imagination) during use of the system	☐	☐	☐	☐	☐
	How would you feel vehicle display interface content provided suggestive of a challenge to master something	☐	☐	☐	☐	☐
	How would you feel vehicle display interface content catered explicit distinctions between gender and age	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system used aesthetic appeal and poetry as a way of gaining user's attention	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system encouraged personal opinion	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system used images of materialism or consumerism to gain the user's attention	☐	☐	☐	☐	☐

	How would you feel if vehicle display interface system contained official slogan or local or national symbol in the display content	☐	☐	☐	☐	☐
	How would you feel if the display menu navigation styles in vehicle display interface system were structured in a way that allows user to complete tasks quickly and avoid distraction	☐	☐	☐	☐	☐
	How would you feel if the display menu navigation styles in vehicle display interface system were complex to use	☐	☐	☐	☐	☐
Dysfunctional	How would you feel if vehicle display interface system did not provided highly structured information access for the system	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system did not provided images of local hero or leader in the display content	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system did not provided minimal menu options	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system did not provided descriptive text on each menu options	☐	☐	☐	☐	☐
	How would you feel if vehicle display interfaces system did not provided many menu options	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system did not provided abbreviated text on each menu options	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system did not provided icon on each menu options	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system did not provided quick results for limited tasks (limited button press options)	☐	☐	☐	☐	☐
	How would you feel if vehicle display interfaces system did not allowed user exploration (challenge user imagination) during use of the system	☐	☐	☐	☐	☐
	How would you feel vehicle display interface content did not provided suggestive of a challenge to master something	☐	☐	☐	☐	☐
	How would you feel vehicle display interface content did not catered explicit distinctions between gender and age	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system did not used aesthetic appeal and poetry as a way of gaining user's attention	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system did not encouraged personal opinion	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system did not used images of materialism or consumerism to gain the user's attention	☐	☐	☐	☐	☐
	How would you feel if vehicle display interface system did not contained official slogan or local or national symbol in the display content	☐	☐	☐	☐	☐
	How would you feel if the display menu navigation styles in vehicle display interface system did not structured in a way that allows user to complete tasks quickly	☐	☐	☐	☐	☐
	How would you feel if the display menu navigation styles in vehicle display interface system were not complex to use	☐	☐	☐	☐	☐

Appendix IX Tasks Lists used in the Application Study

Tasks Categories		*Actual Tasks*	*Total Category tasks*	*Code*
Media Player	"You like to hear music from the vehicle Media Player".		5	
	i.	"Please find and select 'Media Player' function of the vehicle display touchscreen system".		*t1*
	ii.	"Please find and select the next track command and proceed to the next song".		*t2*
	iii.	"Please adjust the volume of the media player to your desired level".		*t3*
	iv.	"Please find and select the 'Random' function from the media player display screen".		*t4*
	v.	"Please find and select the mute function from the media player display screen".		*t5*
Radio Control	"You like to change source to 'Radio'. Please find and select 'Radio' function from the source list"		5	
	i.	"Please find and select 'Radio' function from the source list".		*t6*
	ii.	"Please change the 'Radio Band' to FM".		*t7*
	iii.	"Please save currently played radio station to the 'favourite list'".		*t8*
	"You like to select a station based on your choice of program type".			
	i.	"Please navigate to Program Type menu list and select a radio station based on your choice of 'Current Affairs" program category".		*t9*
	"You like to see textual information that is broadcasted by the station".			
	i.	"Please select 'Text' to see what is broadcasted now by the radio station".		*t10*
Bluetooth Telephone	"You like to connect your Bluetooth phone with the vehicle display touchscreen user interface".		6	
	i.	"Please find and select 'Search Devices' function of the vehicle display touchscreen system".		*t11*
	ii.	"Once the phone is discovered, please find and select 'Pair Phone' function and connect the mobile phone with the vehicle as per display instruction".		*t12*
	"You like to read an incoming text message from the vehicle display touchscreen system".			
	i.	"Please find and select 'Read messages' function from the telephone menu list".		*t13*
	"You like to make an outgoing call".			
	i.	"Please find Mr. Piyush Agarwal's contact information by using the scroll down option from telephone contact list".		*t14*
	ii.	"Please make a call to Mr. Piyush Agarwal on +91(0) XXXX-XXXX006".		*t15*
	"You have received an incoming call in your vehicle Bluetooth telephony system".			
	i.	"Please accept the incoming call from Mr. Piyush Agarwal".		*t16*
Navigation Map	"You need to find a house located in the East of Pune city".			
	i.	"Please enter this address (XXXX….Pune 411001) as a destination into the navigation map".	6	*t17*
	"You have reached your destination. You need to find a car park near to the address".			
	i.	"Please find and select car park category in 'Point of Interest' (POI) list and select the first item from the list. Please press 'Go' once selected".		*t18*
	"You want to view a map of your vehicle and the surrounding area where you are located".			
	i.	"Please bring up the navigation map of your current location onto the display screen to it".		*t19*
	ii.	"Please change the orientation of the map so that display is oriented northward".		*t20*
	iii.	"Please adjust the display view mode from day-time to night-time mode".		*t21*
	"You like to go to a previously stored navigation address from the destination address list and navigate".			
	i.	"Please find and select previously stored navigation addresses and select 'XXXX….Pune 411001' from the list items".		*t22*
Menu Control	"You like to delete the stored song from 'Media Player' source menu list".		3	
	i.	"Please scroll down two pages to the XXXX song".		*t23*
	ii.	"Please select the song from the list".		*t24*

	iii.	"Please delete the song (item) from the list".		*t25*
Menu settings	"You like to adjust the sound system of the vehicle. Please find and select 'Sound Settings' function".		4	
	i.	"Please adjust navigation voice guidance volume settings to your desired level".		*t26*
	ii.	"Please adjust phone volume settings to your desired level".		*t27*
	iii.	"Please adjust music sound system (Bass, Treble, Stereo, Mono) to your desired level".		*t28*
	iv.	"Please adjust 'Traffic Interruption' (TA) volume settings to your desired level".		*t29*

Appendix X Innovation Score from Journal Paper Review

SAE MyTechZone

SAE 2014 World Congress & Exhibition > Multi-Media Systems (AE307) >

14AE-0035/2014-01-0263 - A Study of Cultural Influence in Automotive HMI: Measuring Correlation between Culture and HMI Usability

View : Manuscript

11/19/2013	Reviewer #: 98851				
Conclusions	Archival	Integrity	Quality	Presentation	Innovative
8	9	10	7	8	10
					Revision History
No Comments Available.					

01/14/2014	Reviewer #: 99387				
Conclusions	Archival	Integrity	Quality	Presentation	Innovative
10	10	10	10	10	10
					Revision History
No Comments Available.					

01/15/2014	Reviewer #: 104328				
Conclusions	Archival	Integrity	Quality	Presentation	Innovative
8	9	10	9	9	9
					Revision History
No Comments Available.					